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A SURVEILLANCE STRATEGY FOR A FOUR YEAR OPERATING CYCLE IN COMMERCIAL PRESSURIZED WATER REACTORS

by

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Submitted to the Department of Nuclear Engineering
in Partial Fulfillment of the Requirements for the
Degrees of Nuclear Engineer and
Master of Science in Nuclear Engineering

at the
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May 1996

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A SURVEILLANCE STRATEGY FOR A FOUR YEAR OPERATING CYCLE IN COMMERCIAL PRESSURIZED WATER REACTORS

by

Thomas J. Moore, Jr.

Submitted to the Department of Nuclear Engineering
on May 10, 1996 in partial fulfillment of the requirements
for the Degrees of Nuclear Engineer and
Master of Science in Nuclear Engineering

ABSTRACT

If the U.S. nuclear industry hopes to remain competitive and grow into the next century, it must be willing to expand the goal of each plant from safe performance, to safe and economic performance, and apply this type of thinking in all its decision making processes. Economic performance can be improved by increasing the plant capacity factor. However, the current industry cycle lengths of 18 to 24 months are limited in the capacity factor gains they can achieve. The nuclear industry should consider focusing on strategies that will extend operating cycles to 48 months or more. Such a strategy should address required reliability and availability performance, and the surveillance requirements needed to attain a 48 month goal.

A surveillance strategy necessary to achieve a 48 month fuel cycle was developed. The primary goals and objectives of the strategy were to overcome the regulatory and investment protection barriers to extended cycle lengths, provide a systematic surveillance resolution procedure, and provide a framework for addressing plant forced outage rates. As part of the strategy, a detailed methodology for determining the surveillance performance options necessary to achieve a 48 month fuel cycle was produced. The methodology was applied at an operating Westinghouse Pressurized Water Reactor to demonstrate the viability of a 48 month cycle within the nuclear industry. Of the 3108 regulatory and investment protection surveillances studied, 3054 would likely support an extended fuel cycle. Initial recommendations are provided for resolving the remaining 54 surveillances which are potential barriers to an extended cycle. The framework for reducing forced outage rates was applied to a key plant component, the Main Feed Pump. The framework concluded that the Main Feed Pump is likely to operate reliably over 48 months and not have a significant impact on the overall plant forced outage rate.

One of the key concepts discussed is the use of the Limiting Plant Event Frequency (LPEF) as a measure of expected loss in making surveillance program economic decisions. The LPEF includes the Core Damage Frequency (CDF), but also recognizes the importance of other transient endstates not affecting CDF whose economic consequences are so severe that they must be avoided with the same urgency applied to core damage.

Thesis Supervisor: Neil Todreas
Title: Professor of Nuclear Engineering

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Chapter 1 - Introduction

1.1 Impetus

Heading into the 21st century, the nuclear power industry is at an important crossroads. Faced with increasing competition from the coal and gas industries and a much stricter regulatory environment, the nuclear industry must focus on strategies that will improve its economic performance and make it an attractive alternative to other major electric power producing options. Only by pursuing these strategies will the nuclear industry guarantee its short term survival and position itself for long term growth.

Conventionally fueled power plants start with an immediate economic advantage over nuclear plants because of lower construction costs and interest payments, lack of up front decommissioning costs, less regulatory costs, and typically much smaller plant staffing levels. To offset these built in economic advantages the nuclear industry must maximize its one clear advantage over all its major electric power producing competitors, significantly lower fuel costs. Once on-line, a nuclear power plant's lower fuel costs can give it a decided economic advantage over other electric power producing options if the number of operating or on-line days significantly outnumber the number of days shutdown and it operates at full capacity.

The term typically used to measure the economic performance of nuclear power plants is capacity factor. Capacity factor is defined as the amount of electricity produced over a given time period divided by the amount of electricity which could have been produced if the plant had run at 100% power for the entire period. Since nuclear power plants rarely operate at power levels much below 100% power, the major determinant in capacity factor increases is the ratio of on-line days to the sum of on-line and off-line days during any given time period. Off-line days are caused by either forced or planned outages. Forced outages result from either plant system failures or operator errors. Planned outages are used to perform refueling operations, preventative and corrective

maintenance, and system testing. Thus, any strategy designed to improve plant capacity factors, and hence economic performance, must focus on maximizing the number of on-line days during any given time period. This can be accomplished by focusing on three key areas. These are:

- Increasing the cycle length between refuelings
- Minimizing refueling and planned maintenance outages times
- Reducing forced outage rates

The U.S. nuclear industry has already realized some of the potential economic gains from longer operating cycles. While most plants operated on fuel cycles as short as 12 months just a decade ago, most now operate on an 18 month fuel cycle and approximately 17% of the industry has made or is now making the transition to 24 month fuel cycles. The rationale for extending to a 24 month cycle has been both the improvement in lifetime capacity factors and the elimination of one refueling outage every six years as compared to an 18 month cycle. Although there remains some skepticism within the industry as to the economic benefits of adopting a 24 month cycle, it is apparent that, despite some initial setbacks caused primarily by not anticipating all the possible problems associated with cycle length extension, 24 month fuel cycles are cost effective. Seabrook Station, for example, estimates a net savings of $29 million over a six year period by transitioning from an 18 month to a 24 month operating cycle. Of this total savings, $25 million comes from the elimination of one refueling outage every six years.[1]

Given the economic benefits already realized from increasing cycle lengths from 12 months to 24 months, the next logical question is, are there even more economic benefits available by achieving even longer cycle lengths on the order of 48 months or more? This hypothesis was tested by Dalporto/Todreas in their work entitled "Achieving Higher Capacity Factors in Nuclear Power Plants Through Longer Operating Cycles" (MIT-ANP-TR-030). This research combined extensive interviews with industry leaders with a

[1] O'Regan, Patrick J., 24 Month Fuel Cycle Evaluation, December 1994.

simplified economic analysis. It concluded that the potential benefits to the U.S. nuclear industry from longer operating cycles were significant and provided a general strategy for how cycle lengths of this magnitude might be achieved. Given a 35 day refueling outage (already achieved by the best performing plants), the maximum theoretical capacity factor for various cycle lengths, assuming no forced outages, would be as shown in Table 1.1.

Capacity Factor Potential Given a 35 Day Refueling Outage

Table 1 - 1

Cycle Length	Maximum Capacity Factor
12 Months	90.5%
18 Months	93.5%
24 Months	95%
48 Months	97%

Given that each 1% increase in capacity factor results in an approximate economic benefit of $2.19 million/year (based on $0.6 million per effective full power day), research efforts to develop a comprehensive strategy for obtaining a 48 month fuel cycle are clearly warranted.

Such a strategy should address the following areas:

- Core Design Issues. A fuel core should be designed which is capable of a nominal 48 month lifetime. For practicality, it should fit into existing nuclear power plants and the fuel burnup should be maintained at or below current licensing limits.

- Required Reliability and Availability Performance. A strategy for attaining the plant levels of reliability and availability needed to reduce forced outages and make a 48 month operating cycle economically attractive should be formulated.
- Surveillance Requirements. All maintenance and testing activities, termed surveillances, which a utility is currently required to perform off-line at intervals less than 48 months must be made consistent with a 48 month cycle. Resolution can be in one of three forms: the surveillance's performance interval can be extended to at least 48 months, the surveillance's performance mode can be changed from off-line to on-line performance, or in some cases, the surveillance can be eliminated.

This thesis focuses almost exclusively on the development of a strategy to establish surveillance requirements which support a 48 month operating cycle in commercial Pressurized Water Reactors (PWR). An initial investigation into the reliability of one key PWR component (the Main Feed Pump), and its possible impact 48 month cycle forced outage rates is begun as the groundwork for more extensive future work on industry forced outage rates.

1.2 Goals and Objectives

Important untested speculations against extended fuel cycles have always included a perception that the regulatory and economic barriers to making the required regulatory based and investment protection surveillances compatible with longer operating cycles were just too difficult to overcome, the inability of plant equipment to run for extended periods of time between maintenance, and the economic costs associated with a longer core life. But, the first two arguments have never been thoroughly investigated. If the surveillance requirements can be adjusted to allow longer operating cycles, and equipment can be operated with reduced forced outage rates over a 48 month cycle, the financial penalties of operating a longer life core could be outweighed by the economic gains associated with the increased plant capacity factor. In order to test this hypothesis, the following primary goals and objectives have been developed:

- Overcome the regulatory and investment protection barriers to extended cycle lengths
- Provide a systematic surveillance resolution procedure that utilities can use to prepare for extended cycle lengths
- Develop an initial framework for a key plant component to show how key plant components can operate for extended periods of time between maintenance without adversely impacting the plant forced outage rate.

1.2.1 Overcoming Regulatory and Investment Protection Barriers

Too often in the beginning phases of this work, and during Dalporto/Todreas's initial exploration of the possibility of extended cycle lengths, nucleaer industry personnel stated that they thought that the performance schedule of most of the surveillances they performed could be adjusted to support extended cycle length operations. But, they also stated that the regulatory barriers, imposed by the Nuclear Regulatory Commission (NRC) and other state and local agencies, that had to be overcome to move towards an extended cycle were just too difficult to change and thus did not warrant attempting cycle lengths beyond the current maximum of 24 months. One utility executive, from a very successful plant already using a 24 month fuel cycle, explained that he felt that many utilities were using the regulatory barriers as an excuse not to pursue longer cycle lengths, because they found the work necessary to get there "just too hard." His experience, however, was that if one were willing to do the work necessary to provide a sound engineering and technical basis for requests to the NRC, the perceived barriers could be overcome. This experience was backed up by comments received in interviews conducted with senior NRC management about the 48 month cycle who reiterated the fact that although they thought it would be difficult, extended fuel cycles were possible and that regulatory concerns could be satisfactorily resolved if the proper technical case could be made.

Chapter 2 of this report presents a methodology for identifying the surveillance performance options necessary to overcome the regulatory and investment protection

barriers to a 48 month operating cycle. The methodology can be applied to each surveillance which currently precludes a 48 month cycle. A decision chart identifies the possibilities for resolution with an extended fuel cycle. The methodology yields a recommendation that the particular surveillance is either a candidate for on-line performance (Category A), a candidate for performance interval extension (Category B), or a potential impediment to a 48 month fuel cycle which requires further study (Category C). Chapter 3 shows how this methodology could be applied to resolve the entire set of PWR plant surveillances to a 48 month cycle by using the actual surveillance program from an operating PWR.

An area of study that should be developed in the future is the optimization of surveillance categorization. The methodology of Chapter 2 identifies the surveillance performance possibilities for those surveillances currently precluding a 48 month fuel cycle. Some surveillances will be candidates for both on-line performance or off-line performance at extended intervals. For surveillances meeting these criteria, a decision must be made as to the optimum choice. A project to develop a model that could choose the best option for each surveillance to maximize the economic benefits of this entire set of surveillances (given no overall change in plant risk) should be considered.

1.2.2 Providing a Procedure for Utilities

After developing a methodology for overcoming the regulatory and investment protection barriers, the thesis demonstrates that the blueprint approach laid out in the Surveillance Resolution Methodology in Chapter 2 is viable and provides a procedure for utilities to apply to their entire surveillance package. Chapter 3 answers the question, "What kind of results can a typical PWR expect if an extensive '48 Month Fuel Cycle Surveillance Resolution Study' is carried out?" The regulatory and investment protection surveillance requirements of an operating PWR transitioning to a 24 month cycle were analyzed. Utilizing the methodology presented in Chapter 2 as a framework, surveillance

performance procedures and historical surveillance records were used to identify possible candidates for on-line performance (Category A), off-line performance at 48 month intervals (Category B), and those surveillances which are likely to preclude a 48 month cycle and require further study (Category C). Plant personnel were consulted to ensure surveillance classifications were appropriate. Ultimately, expert judgment was relied upon to assign final individual surveillance categorizations. Chapter 4 compiles all the surveillances placed in Category C. Some discussion of the possible solutions to these surveillances is provided.

As part of the detailed surveillance resolution procedure, Appendix A provides detailed instructions for completion of technical evaluations necessary to support surveillance performance interval extension. Additionally, Chapter 5 provides an interval extension justification that was used as the basis for an actual 24 month interval extension request at the candidate PWR. The format of this example provides a general guide to utilities for how to justify a surveillance's performance interval extension. By presenting an interval extension justification, Chapter 5 illustrates the effort required to complete a 48 month fuel cycle surveillance resolution project. For this thesis, complete justification of all candidate surveillances was a prohibitively large task. Also, it was assumed that actual surveillance resolutions will vary somewhat from plant to plant. Consequently, complete surveillance justification is left to the individual utility.

Finally, Chapter 7 is a compilation of management principles and engineering points of interest related to an extended fuel cycle. It answers the question, "What are some of the major management and engineering issues which should be kept in mind when pursuing surveillance requirement resolution?" Topics discussed include on-line surveillance scheduling aids, methods of transition to an extended cycle, mid-cycle maintenance outages, and others.

1.2.3 Initial Framework for Reducing Forced Outage Rates

Chapter 6 investigates the reliability levels of the Main Feed Pump (MFP) and its impact on plant forced outage rates. Industry data was compiled to provide an estimate of the current reliability levels. Additional research and interviews with industry representatives, pump vendors, pump consultants, and the vendors of key pump sub-components was conducted to determine the major failure mechanisms, root causes of failure, and recommendations for improving the reliability of the MFP. The primary purpose of Chapter 6 was to develop a framework for use in making decisions on whether key plant components could economically be made to operate reliably for 48 months without adversely impacting the overall plant forced outage rate. Chapter 6 lays the groundwork for significant future work on other key plant components that are major contributors to the overall plant forced outage rate.

1.3 Safe Performance versus Economic Performance

There is common misconception by some within the nuclear industry that by emphasizing economic performance, one sacrifices safety and vice versa. A close look at industry performance measures in the past decade helps break that paradigm. Following the Three Mile Island accident in 1979 there was an enormous increase in the regulation and oversight of the nuclear industry. An even higher emphasis was placed on safe operation in an attempt to regain credibility and public confidence. Yet, despite the increased emphasis placed on safe operation, which on the surface might appear to conflict with what is needed to improve plant economic performance, the industry has seen an unprecedented rise in the average plant availability (a measure of economic performance) in the last decade while at the same time the average number of automatic scrams and significant events per plant (measures of safe performance) have dropped significantly. This data, provided by the NRC, is shown in figure 1.1.

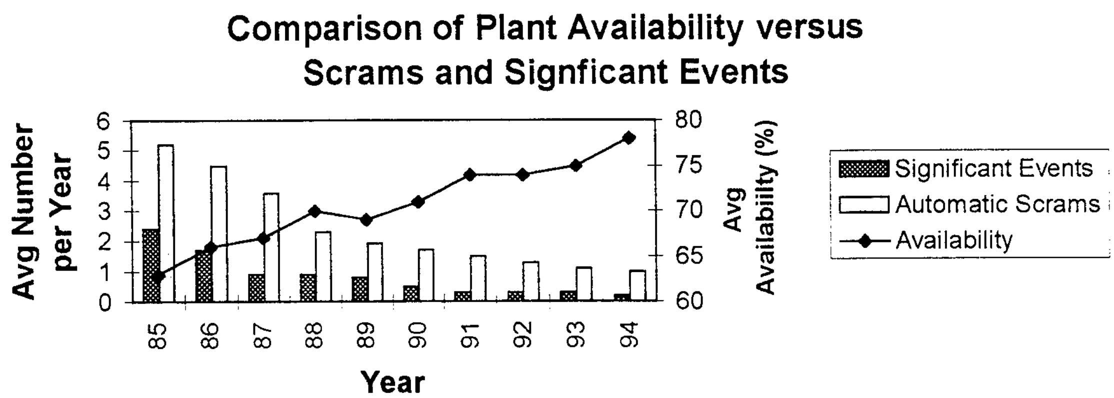

Figure 1 - 1

Figure 1.1 validates the hypothesis that as the industry has become safer, as indicated by the lower number of significant events, the better the plants perform, as indicated by both the reduced number of automatic scrams and the increase in availability. Assuming that the average power plant earns about $600,000 per effective full power day, the 11.4% increase in availability in 1994 as compared to 1986 resulted in $24.98 million in additional revenue in 1994 alone. The total savings from 1986 to 1994 were $110.45 million. In an industry struggling to maintain its viability into the next century this is a significant amount of additional revenue which can either be returned to investors as dividends or to the end users in the form of lower electric rates.

1.4 Terminology

The author has attempted as much as possible to use terminology that is standard within the nuclear industry. For clarity, the following terms are defined here.

- Surveillance - A planned maintenance or test performed to meet either regulatory requirements or for investment protection purposes.
- Investment Protection - A class of surveillance, voluntarily performed by a utility to protect components or systems vital to plant operation, in which they have invested significant amounts of capital.

- Performance Mode - The standard technical specification definitions which describe reactor state in terms of power and temperature. The defined modes are:

Mode 1	Critical(> 5% Power)	>350°F
Mode 2	Critical(<5% Power)	>350°F
Mode 3	Shutdown	>350°F
Mode 4	Shutdown	200-350°F
Mode 5	Shutdown	<200°F
Mode 6	Refueling	<140°F

Chapter 2 - Surveillance Resolution Methodology

2.1. Introduction

Some of the methodology presented in this chapter was developed jointly between myself and John Maurer who worked concurrently on a similiar thesis titled "Surveillance Strategy for a Four Year Operating Cycle in Commercial Boiling Water Reactors.", February 1996. The joint work was conducted for the MIT Extended Fuel Cycle Project team under the ausipices of the MIT Program for Advanced Nuclear Power Studies. The results of this work are presented in report MIT-ANP-TR-036 titled "Surveillance Strategy for a Four-Year Operating Cycle in Commerical Nuclear Reactors", May 1996. I footnote the portions of this chapter which were developed individually by Maurer.

The term 'surveillance' is broad in scope. As used in this report, it defines a variety of component tests, inspections, overhauls, and preventive maintenance activities. For example, surveillances include diesel generator operability tests, accumulator integrity inspections, electrical breaker overhauls, and valve internals preventive maintenance activities. A typical nuclear power plant may conduct more than one thousand different surveillances per fuel cycle.

In order to achieve a four year fuel cycle, the performance mode or the performance interval of all plant surveillances performed at intervals less than 48 months while the reactor is shutdown must be resolved. There are two fundamental ways a surveillance can be conducted to support a 48 month operating cycle. The surveillance can be performed while the plant is at power or the surveillance performance interval can be extended to at least 48 months.

This chapter discusses these two surveillance resolution paths in depth and presents a methodology for determining the resolution options a plant has for its individual surveillances. The methodology is presented in the form of two flowcharts. The flowcharts lead to a recommendation for each surveillance. The recommended categories are the following:

- Candidate for on-line performance
- Candidate for performance interval extension,
- Candidate for either on-line performance or interval extension, or
- Requires further study

The chapter then proposes an optimization model for those surveillances which can be performed either on-line or at extended intervals. This model would provide as an output the most economic combination of surveillance performance modes and surveillance performance intervals for the entire set of surveillances while maintaining plant risk levels unchanged.

2.2. Surveillance Resolution Options

2.2.1 Definitions

For the purposes of this thesis, surveillances will be placed in one of three categories which define their probable compatibility with a 48 month fuel cycle. The categories are defined as follows:

Category A - Surveillances which are candidates for on-line performance.

Category B - Surveillances which are candidates for performance interval extension to 48 months.

Category C - Surveillances which are possible barriers to a 48 month cycle and require further engineering assessment to determine whether compatibility with a 48 month fuel cycle can be accomplished

2.2.2 Category A - On-Line Surveillance Performance

During the 1980's, the U.S. nuclear industry began a concerted effort to reduce the length of refueling outages. The driving force was the economic benefit from returning plants to an operational status as soon as possible. Lost revenues from outage

days in the nuclear industry range from \$500,000 per day to over \$1,000,000 per day for utilities where nuclear capacity is less than or equal to demand. Given the loss of revenue, efforts to reduce outage length by even a few hours is justifiable.

The first mechanism used to achieve shorter refuel outages was improved outage planning. Outage efficiency was improved by maximizing the number of surveillances performed simultaneously, thus reducing the total amount of time the plant was off-line.

Once outage efficiency was improved, plant managers focused their attention on moving surveillances to on-line performance modes. This resulted in a substantial increase in the number of surveillances performed on-line and has been the focus of reviews by many major nuclear power organizations, including the Nuclear Regulatory Commission[2] (NRC).

Besides economics, there are many other advantages to increased on-line surveillance performance besides reduced outage lengths. These include the greater attention which can be afforded surveillances performed on-line, a leveled workload over the course of an operating cycle, and labor cost reductions from the more efficient use of full-time employees rather than more expensive outside contractors. These and other factors are discussed below.

Utilities should analyze the on-line performance possibilities of all surveillances, even those which are not part of the outage's critical path. While justifying a surveillance for on-line performance may not result in a direct refueling outage length reduction, it may shorten the outage indirectly by freeing up time for emergent maintenance which often becomes the critical path during refueling outages

During refueling outages, the number of tasks performed and the increased manning levels generate a degree of fatigue and complexity not experienced during normal plant operations. Senior engineering oversight gets stretched thin when so many people are performing so many different activities at once. In contrast, on-line surveillance

[2] "Evaluation of On-Line Maintenance", Temporary Instruction 2515/126, Nuclear Regulatory Commission, 27 October 94.

performance can be afforded much more oversight and planning. Consequently, on-line surveillance performance may result in higher quality maintenance and more precise test execution. However, on-line maintenance can also increase the risk of plant trips and transients if poor maintenance practices are not corrected.

Another human factor advantage associated with performing a surveillance on-line is the increased probability of it being performed by full-time plant employees rather than more expensive outside contractors. The magnitude of the work to be done during a refueling outage and the incentive to minimize the outage length means that outside contractors are often hired to perform a significant portion of the surveillances during an outage. If a surveillance can be performed on-line, the relatively light daily plant workload facilitates surveillance performance by full-time plant personnel. This results in two direct benefits. The first is the increased attention afforded the surveillance which is likely since the plant employee has an ownership stake in the day to day performance of the component or system. The second direct benefit resulting from surveillance performance by plant personnel is increased component and tasking familiarity. Reading the report of a surveillance performed by a contractor can only communicate a certain degree of component status. Having someone on-site everyday who performed the latest diagnostic checks of a component and is intimately aware of the results of those checks is extremely valuable. Such a person is more likely to understand potential failure mechanisms and remember trends in component performance.

Along with advantages in human factors from performing a surveillance on-line, some surveillances are simply safer to do while the plant is operating. For example, from a risk standpoint, the Residual Heat Removal (RHR) System plays a larger safety role when the plant is being shutdown then when it is on the line. Therefore, surveillances which require the RHR system to be inoperable are safer from a risk standpoint to perform on-line. In the case of the RHR system, performing the applicable surveillances during an outage could limit the plant's ability to successfully cope with a Loss of Cooling Accident (LOCA) and raise the core damage frequency (CDF).

Another incentive for justifying surveillance on-line performance is that the surveillance performance frequency can be increased if required. If a component demonstrates poor performance, non-intrusive surveillance performance may assist in predicting component failure. Failure mechanisms can then be diagnosed and corrected before catastrophic component failure occurs. In this way, on-line surveillance performance provides an enhanced component monitoring capability. This monitoring capability may ultimately result in improved equipment performance. If preventive maintenance and diagnostic checks can be performed whenever a problem is suspected rather than at set intervals (dictated by the refueling outages), then problems can be avoided. Fewer catastrophic failures can extend component life. For example, if the oil can be changed on-line whenever a motor exceeds a certain amount of run time rather than at set calendar intervals the motor will likely last longer.

While there are many advantages to on-line surveillance performance, it is not risk free. The safety and economic impacts of taking systems out of service for surveillance performance must be carefully considered prior to any on-line work. On-line, Probabilistic Risk Assessment (PRA) based risk monitors can play an important role in pre-surveillance planning. They greatly enhance a surveillance scheduler's ability to identify potentially hazardous system configurations. However, they do not consider economic risks from on-line surveillance performance. Nor are they are substitutes for thorough preparation and training of the workers who will actually be performing the surveillance. Senior management must ensure that everyone involved in on-line surveillance performance understands the possible complications of the proposed work. Surveillance performance can often have a significant effect on other seemingly independent equipment. For example, many instrument calibrations are fairly routine when they are performed during an outage. But, if they are performed on-line, simply valving an instrument in and out of the system can cause potentially dangerous fluctuations in other instruments monitoring vital plant parameters. Workers must thoroughly understand critical system interdependencies such as these when they perform any surveillance during power operations.

2.2.3 Category B - Performance Interval Extension

During the early years of the nuclear power industry, plant engineers had very little operating experience upon which to base component reliability judgments. Consequently, it was not unusual for plants to shutdown every few months to test vital systems. While the industry has progressed beyond this 'test to see if it's broke' mentality, many current surveillance intervals are still indirectly a consequence of that reasoning. Intervals started out short and have been gradually extended to meet plant requirements, not necessarily as determined by component performance. Consequently, many performance intervals have not been optimized. Instead, they have been chosen so that they meet two conditions; one, that they are conservative, and two, that they support the current plant operating cycle length. This second condition is evident in the non-quantitative surveillance performance extension requirements mandated by NRC Generic Letter 91-04 for utilities going from 18 to 24 month fuel cycles. Extension requests rely on expert opinion and historical surveillance data to make the case that a surveillance interval can be safely extended. This method is chosen because no quantitative methodology for optimizing performance intervals currently exists. An optimization methodology will facilitate justifying the extension of performance intervals for surveillances which currently have overly conservative performance intervals. If a component has been in service for a significant period and has never failed or been found out of specification, it is reasonable to question the whether the performance interval can be increased. Surveillance performance requires time and labor. Resources are poorly allocated if they go toward over-testing a proven component. Frequent testing can also result in equipment wear-out.

Another new maintenance approach which will aid in interval extension justifications is event-based (instead of time-based) testing. Event based testing is a subset of performance based testing which is widely regarded within the industry as the wave of the future in maintenance strategies. The theory is that if failure mechanisms are predominantly event-dependent rather than time-dependent, a correlation between the events in a component's life such as motor start-up and the required surveillance

performance interval can be determined. The result would be surveillance testing mandated every X motor starts or valve strokes instead of every Y months or years.

2.3. Surveillance Resolution

This section presents a surveillance resolution procedure. This procedure provides a systematic method for determining the resolution options for individual surveillances. Once the various options are identified for each surveillance requirement, a proposed Economic Optimization Model would determine the most economical combination of performance modes for all the surveillances while maintaining current plant risk levels unchanged. The risks involved include those associated with core damage as well as other undesirable economic end-states such as the need for emergency depressurization in a boiling water reactor or feed-and-bleed in a pressurized water reactor. Both types of risks will be analyzed by the Economic Optimization Model. The goals of the Economic Optimization Model will be to provide a surveillance program that will:

- Provide maximum economic benefit
- In the worst case, be risk neutral
- Support a future U.S. nuclear industry goal of 30 day planned outages
- Support a future U.S. nuclear industry goal of 40 forced outage days per cycle
- Minimize the number required of mid-cycle maintenance shutdowns, with a goal of zero shutdowns

2.3.1. Category A Resolution Flowchart

This section discusses how to decide whether on-line surveillance performance is possible. In order to accomplish this, refer to the Category A Resolution Flowchart in Figure 2.2 (a flowchart legend is provided in Figure 2.1). Within this flowchart, the Boolean variable 'A' represents the event that the surveillance can be performed on-line. If A = True, then the surveillance is a candidate for on-line performance. If A = False,

then the surveillance is not a candidate for on-line performance and other options must be investigated.

The various decisions and processes of the Category A Resolution Flowchart are discussed in more detail below:

◊ Can the surveillance be eliminated?

This is a fundamental issue independent of whether the surveillance falls into Category A or B. If performance of the surveillance has no effect on plant safety or reliability, then the surveillance should be eliminated. Additionally, if surveillance performance has only a small effect on plant safety or economic performance and could be compensated for by increasing the frequency of selected on-line surveillances, it may be possible to eliminate the surveillance with no net effect on the overall CDF or economic performance.

◊ Is the component accessible at power?

If a component is not accessible at power either directly or remotely, modifications have to be to made to permit access or the surveillance has to be performed shutdown. Inaccessible equipment includes any components inside the bio-shield or located below the reactor and may also include components that are located in high radiation areas where excess personnel exposure costs may make on-line performance cost prohibitive.

◊ Can modifications be made to render the component accessible?

If such modifications are not possible, then the applicable surveillance cannot be performed on-line, A = False, and surveillance resolution analysis should proceed to the Category B Resolution Flowchart which is discussed later.

◊ Can the surveillance be performed on-line by procedure?

If an on-line performance option already exists in the current surveillance procedure, then a determination must be made as to why the utility currently chooses to perform the surveillance off-line. This could include reasons ranging

from economic cost, a perceived risk of operator errors causing unplanned shutdowns, increased man-rem exposure, or no current incentive to perform the surveillance on-line given current plant cycle and refueling lengths. Whatever the reason, action would have to be taken to ensure that on-line surveillance performance does not constitute an unjustified risk. The risk issue is addressed in the Economic Optimization Model later in this chapter.

Flowchart Legend

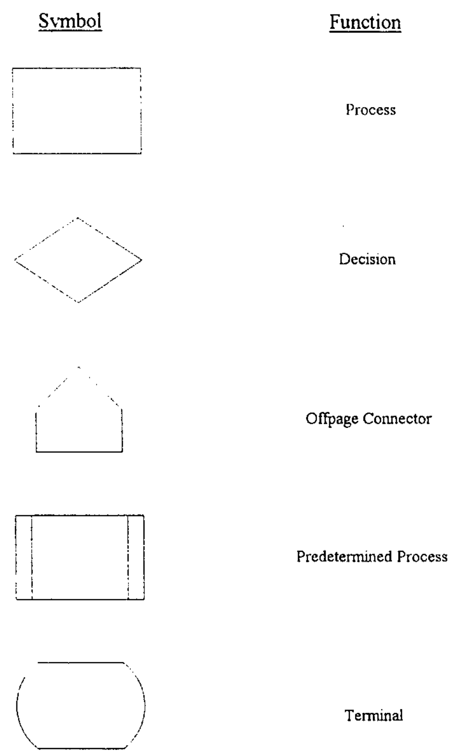

Figure 2 - 1[3]

[3] Maurer, John H. "Surveillance Strategy for a Four Yeare Operating Cycle in Commercial Boiling Water Reactors." MIT Master of Science in Nuclear Engineering Thesis, February 1996 , p. 26.

Category A Resolution Flowchart

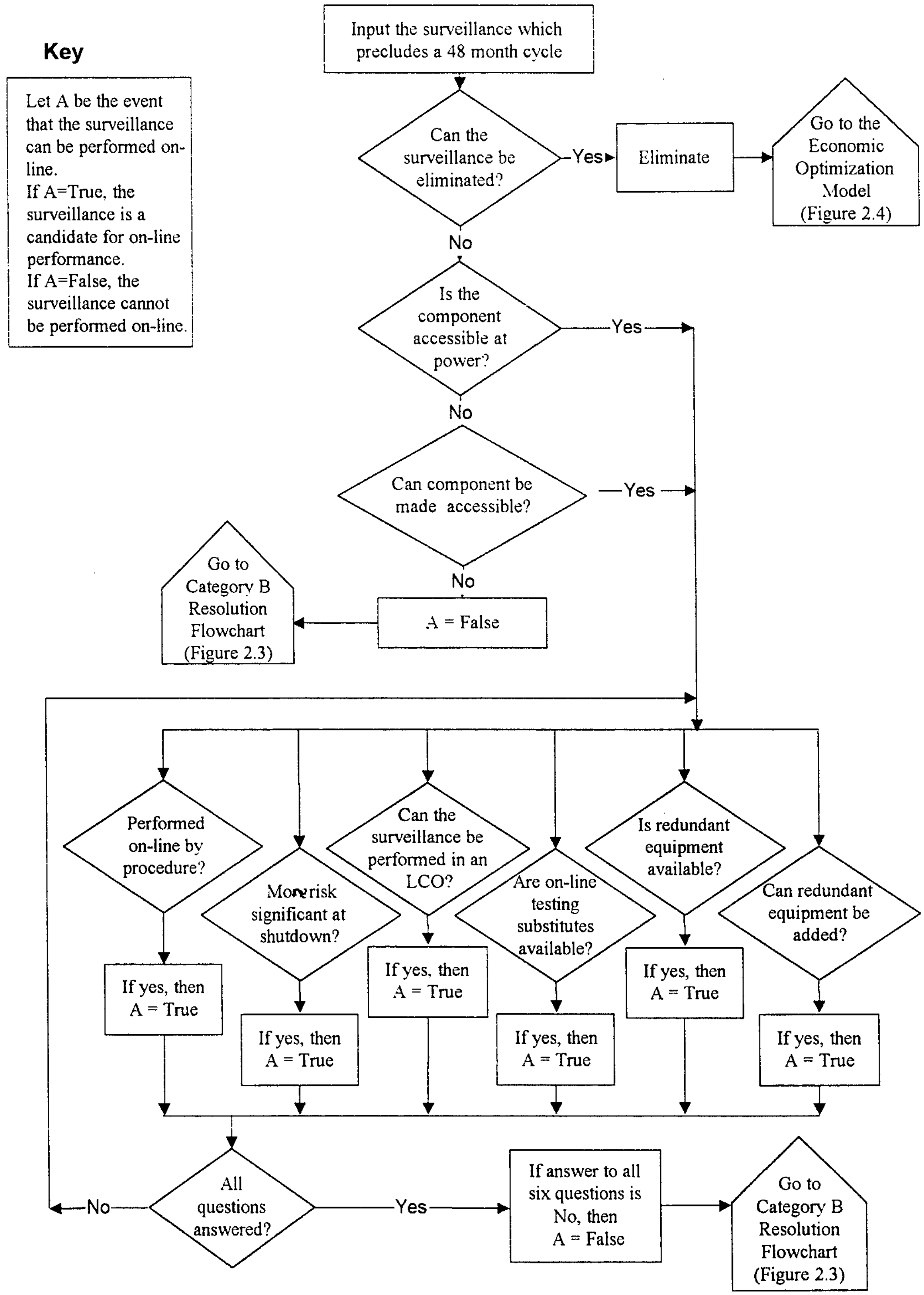

Figure 2 - 2

◊ Is the component more risk significant at shutdown?

Most components/systems which would fall into this category are shutdown safety systems such as the RHR system. In many instances, it would be more desirable to test the system on-line to confirm its operability than to wait for a shutdown condition when its use may be essential.

◊ Can the surveillance be performed in a Limiting Condition of Operation (LCO)?

LCO's are plant configurations, involving the unavailability of a particular component or system, which are allowed for short periods of time by the plant technical specifications. The purpose of an LCO is to minimize unnecessary shutdowns in instances where components or systems can be safely tested on-line and quickly restored to service. In the past, the NRC's position was that LCO's were only to be used for the performance of corrective maintenance. The NRC now allows utilities to enter LCO's in order to perform surveillances on-line provided the utility demonstrates an acceptable understanding of the risks associated with on-line performance and can perform the surveillance within an allowed outage time (AOT). Most utilities have a self imposed time to perform on-line surveillances of 1/2 to 3/4 of the AOT to prevent having to enter an action statement which may mandate a plant shutdown..

◊ Are on-line testing substitutes available?

On-line testing methods such as radiography or ultrasonic testing may provide an alternative to many of the open and inspect surveillances resulting from the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code Section XI. Other testing substitutes could include vibration analysis, thermography, or state of the art lube oil analysis programs.

◊ Is redundant equipment available?

If redundant equipment is available, the component or system can likely be removed from service within an LCO and the surveillance performed on-line. This is particularly applicable to instrumentation where two or more measurement

channels for each parameter are provided. For example, the improved Westinghouse Standard Technical Specifications approved by the NRC specifically allow the removal from service of a redundant channel on reactor protective systems for up to four hours for maintenance or calibration.

◊ Can redundant equipment be added?

The answer to this question depends not only on the component and its function, but also on the layout and space availability of the plant. The cost of adding redundancy is also a prime consideration. Many utility executives interviewed for this report indicated that a utility must be very confident that it will see a return on investment in the first three to four years following major plant modifications before it will make the up front investment required to make the modifications.

If the answer to <u>any</u> of the last six questions above is yes, then A = True and the surveillance is a candidate for on-line surveillance. If the answer to <u>all</u> of the last six questions above is no, then A = False and on-line performance is not an option.

Regardless of whether A = True or False, the next step is to determine whether the surveillance is a candidate for performance interval extension. The Category B Resolution Flowchart is used to make this determination..

2.3.2. Category B Resolution Flowchart

The next resolution task is to decide whether a surveillance is a candidate for performance interval extension. The Category B Resolution Flowchart in Figure 2.3 is used to make this determination. Within this flowchart, the Boolean variable 'B' represents the event that the surveillance performance interval can be extended. If B = True, then the surveillance is a candidate for performance interval extension. If B = False, then the surveillance performance interval cannot be extended. The Boolean variable 'C' represents the event that the surveillance performance interval cannot be extended and the surveillance cannot be performed on-line. C = True if A = False and B = False. If C =

True, then the surveillance requires further study to make it compatible with a 48 month operating cycle.

The various decisions and processes of the Category B Resolution Flowchart are discussed below.

◊ Can the interval be extended on the basis of a technical evaluation?

This will be the primary method for justifying extensions of surveillance performance intervals. NRC Generic Letter 91-04 forms the basis for the technical evaluation. The evaluation must consider issues such as surveillance history, corrective maintenance history, preventive maintenance history, time dependent failure modes, and system engineer technical opinions. If the technical evaluation concludes that the surveillance performance interval can be safely extended, then B = True and resolution analysis should proceed to the Economic Optimization Model.

◊ Can the interval be extended based on a lack of risk significance?

If extending the performance interval of a particular surveillance has a relatively small impact on the overall CDF or economic performance, then its interval can likely be extended. The increase in CDF or the increased economic cost as a result of performance interval extension could be offset by additional on-line testing of other surveillances.

◊ Can the interval be extended by increasing the scope of the surveillance?

If the scope of a surveillance is increased, it may be possible to perform it on a less frequent basis. For example, a particular pump is completely overhauled every 10 years, but an inspection is performed every 24 months while the plant is shutdown. However, if the pump's material history showed that time dependent failures only occurred at frequencies approaching 10 years, than the pump components with the highest time dependent failure rates could be replaced on a more frequent basis

than once every 10 years, allowing the plant to justify extending the inspection interval for the pump to coincide with the replacement of these components.

◊ Can the interval be extended by performing on-line monitoring?

On-line monitoring programs are increasing in use and sophistication. Some of the current on-line monitoring programs include techniques such as vibration analysis of pumps and turbines, acoustic flow detection and monitoring to measure valve performance, radiography, thermography of breakers and pumps, and lube oil analysis. The application of these techniques may allow for actual inspection intervals to be extended. This has the added benefit of reducing the number of times a component must be taken apart for inspection thus introducing more human error into the overall component performance.

◊ Can the interval be extended by upgrading the component?

Many surveillance performance intervals are based on the failure history of particular components. If a superior component or system exists, performance interval extension might be possible by replacing the existing component with the superior performer. Upgrades of components could also entail more elaborate installation and alignment techniques. For example, many pump failures are due to improper or insufficiently precise alignments. An improvement in the alignment of the shaft through the use of a modern alignment technique and proper mounting of the pump could result in improved component performance and reliability which would justify a surveillance performance interval extension.

If the answer to <u>any</u> of the last four questions above is yes, then B = True and the surveillance is a candidate for performance interval extension.

If the answer to <u>all</u> of the last four question above is no, then B = False and the surveillance cannot be performed at extended intervals.

Category B Resolution Flowchart

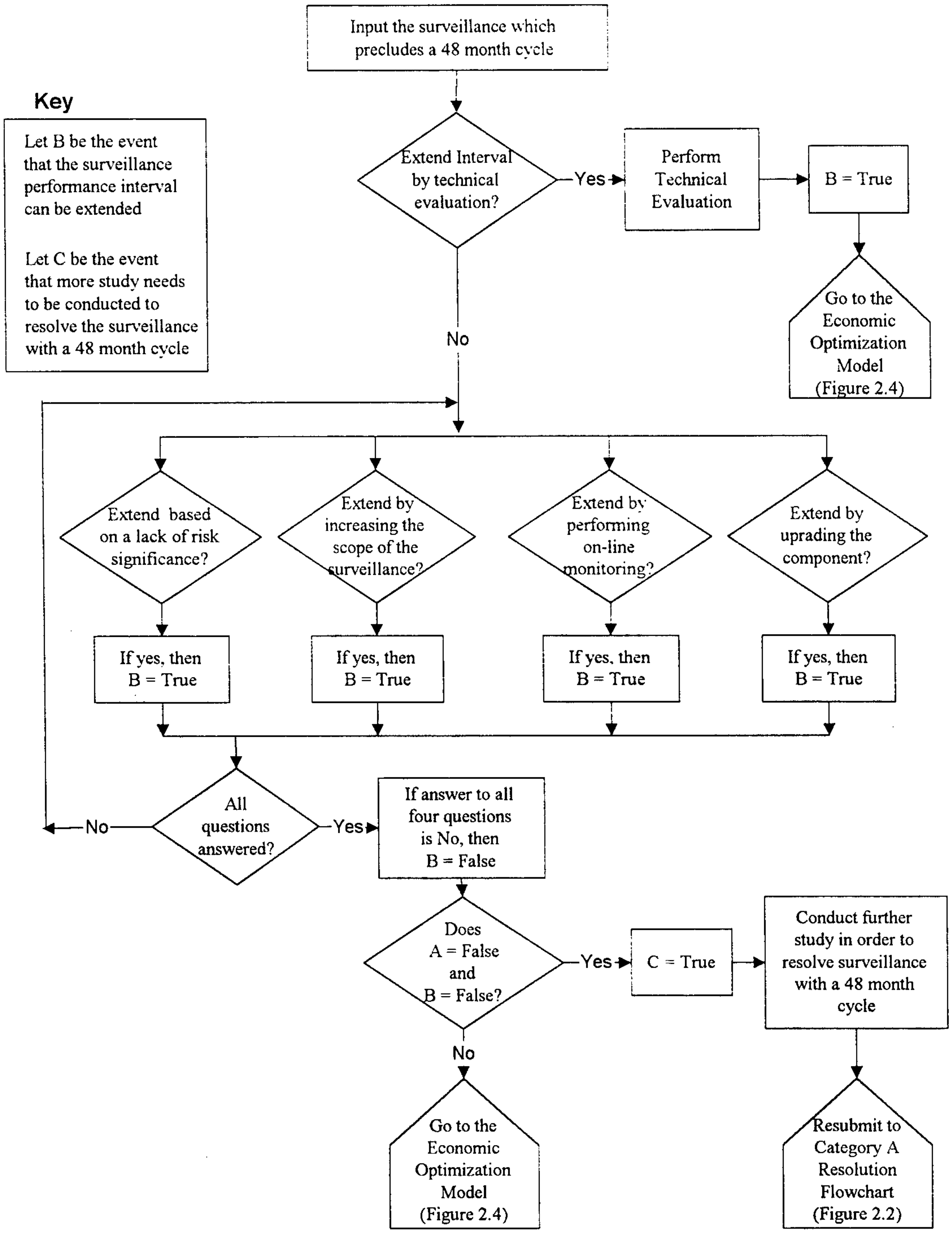

Figure 2 - 3

If A = False and B = False, then the surveillance is classified as Category C and requires further study to resolve it consistent with an extended operating cycle. All other surveillances are input into the economic optimization model.

2.3.3. Economic Optimization Model

The purpose of the Economic Optimization Model, represented in the flowchart of Figure 2.4, is to identify the various surveillance performance variables needed for the proposed Economic Optimization Engine which will be discussed later in the chapter. These variables are required for the Engine to determine the most economic combination of surveillance performance modes while maintaining current risk levels. Variable determination is accomplished in the process boxes of the Economic Optimization Model. (The specific quantification methods for determination of the variables is left as future work.).

Maintaining current risk levels unchanged involves accounting for changes in the probability of core damage as well as other undesirable economic end-states. Limiting Plant Events (LPE), which are events that have a significant economic impact on the plant, define the entire set of risks which must be controlled to achieve economic success. In the past, CDF has been the risk indicator most frequently used by the nuclear industry for making maintenance and operational decisions. Yet, the sole use of CDF in determining plant risk levels does not adequately account for all the important risk considerations. Core damage must obviously be avoided because of the possible consequences to public health and safety. But, core damage must also be avoided because it results in a significant economic impact on the plant, and likely the entire nuclear industry. Therefore, in reality, core damage is a subset of the entire set of LPE's that have a significant economic impact on a plant. Since the rationale behind <u>any length</u> fuel cycle extension program is improved economic performance, the Limiting Plant Event Frequency (LPEF) is the critical factor that must be considered in any surveillance resolution program. Any Economic Optimization Engine must consider all the possible endstates that could lead to a LPE. These would include but are not limited to:

- Any endstate resulting in damage to the Main Turbine or Generator which would require lifting of the turbine casing or generator winding replacement
- Any endstate resulting in severe damage to a Main Feed Pump requiring pump or turbine end replacement
- Any endstate resulting in damage to a Reactor Coolant Pump where the reactor is safely shutdown but loop draining is required to remove and repair the pump
- Any endstate resulting in a BWR reactor depressurization trip with resulting containment contamination
- Any endstate resulting in core damage

In only the last case is core damage an endstate. However, the time required to make the repairs necessary to return the plant to an electric producing (and revenue generating) state in the first four cases is so lengthy and costly, that occurrence of these types of endstates must be avoided with almost the same urgency applied to core damage. Because LPE's are most likely to occur as the result of a major plant transient, their probability of occurrence is likely highest when the plant is at power. Significantly, LPE's may involve systems not included in the technical specifications. While methods to determine changes in CDF have received widespread study and are fairly well understood, LPEF changes have not received the same focus and require more in-depth study to determine how to quantify changes in the LPEF.

Two restraints on the output of the Economic Optimization Engine would be that the mean and extreme LPEF and CDF over the course of the cycle would be no worse than unchanged as compared to the original cycle length values.[4] Although the events contributing to the mean LPEF value include those affecting the mean CDF value, it is possible that improvements in the frequency of other LPE's could mask a large increase in the CDF. Therefore, from a pure safety standpoint, a constraint must also be placed on

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[4] Note that if a percentage decrease or increase in either the integrated LPEF or CDF was required or desired, the Engine could be easily modified to provide this.

the changes in the mean CDF. Another requirement would be that the Engine's recommendations do not contradict the appropriate legal authority, i.e. technical specifications or other legal code. Finally, a limit would be placed on both the instantaneous LPEF and CDF which could be experienced by the plant so that dangerous plant configurations would be avoided.

In the descriptions below, variables are classified as either "given" or "input". A "given" variable concerns a surveillance which has only one possible means of resolution within a 48 month operating cycle. An "input" variable concerns a surveillance which has more than one possible means of resolution within a 48 month operating cycle.

A detailed description of each process box: (the numbers in parentheses refer to the numbers next to the process boxes in Figure 2.4) follows.

- (1) Determine the changes in LPEF and CDF from surveillance elimination

The elimination of a surveillance may increase both or either of the LPEF and CDF of the plant. This increase might be offset by a decrease in the LPEF and/or CDF as a result of either a change in the performance mode or a change in the performance interval of some other surveillance. <u>The changes in the LPEF and CDF as result of surveillance elimination is a "given" variable</u> to the Economic Optimization Engine because no other performance option is considered for surveillance's whose elimination results in large economic savings. Ultimately, the changes in the LPEF and CDF must be accounted for in the output of the Economic Optimization Engine.

- (2) Determine the changes in LPEF and CDF from switching to on-line performance

Switching to on-line surveillance performance may change the LPEF and/or CDF. This change may be either an increase (as in the case where a plant transient resulting from human error may be more likely) or a decrease (as in the case where the surveillance involves a system or component which is more risk significant during shutdown). <u>The changes in the LPEF and CDF from switching to on-line performance for A = True, B = False surveillances is a "given" variable</u> to the Economic Optimization Engine because off-

line performance interval extension is not an option. Ultimately, the changes in the LPEF and CDF must be accounted for in the output of the Economic Optimization Engine.

❒ (3) Determine the changes in LPEF and CDF as a function of the performance interval

When the performance mode of a surveillance is switched from off-line to on-line, increased surveillance performance frequencies become an option. Increasing performance frequencies, for non-destructive surveillances, may result in a decrease in the LPEF and/or CDF (as in the case where a preventive maintenance activity can be performed more frequently). This decrease in LPEF and CDF may be needed to offset a possible increase in LPEF or CDF resulting from changing the performance mode or performance interval of other surveillances. <u>The changes in LPEF and CDF as a function of the performance interval for A = True, B = False surveillances is a "given" variable</u> to the Economic Optimization Engine because off-line performance interval extension is not an option. The Economic Optimization Engine will recommend performance intervals for all A = True, B = False surveillances so that the total net changes in the LPEF and CDF are zero.

❒ (4) Determine the changes in LPEF and CDF from extending the performance interval

Extending the performance interval of a surveillances to make it compatible with a 48 month fuel cycle may result in an increase in the LPEF and/or CDF (as in the case where the operation of an integral safety system will be verified less frequently). <u>The changes in LPEF and CDF from surveillance performance interval extension for A = False, B = True surveillances is a "given" variable</u> to the Economic Optimization Engine because on-line surveillance performance is not an option. Ultimately, the changes in the LPEF and CDF must be accounted for in the output of the Economic Optimization Engine.

❒ (5) Determine the time required to perform the surveillance

During a refueling outage surveillances can be performed in parallel with refueling operations without any additional increase in outage length. It is assumed that utilities already employ parallel path surveillance planning tools to help minimize outage lengths. Once the core is completely refueled, however, surveillance performance generally

Economic Optimization Model

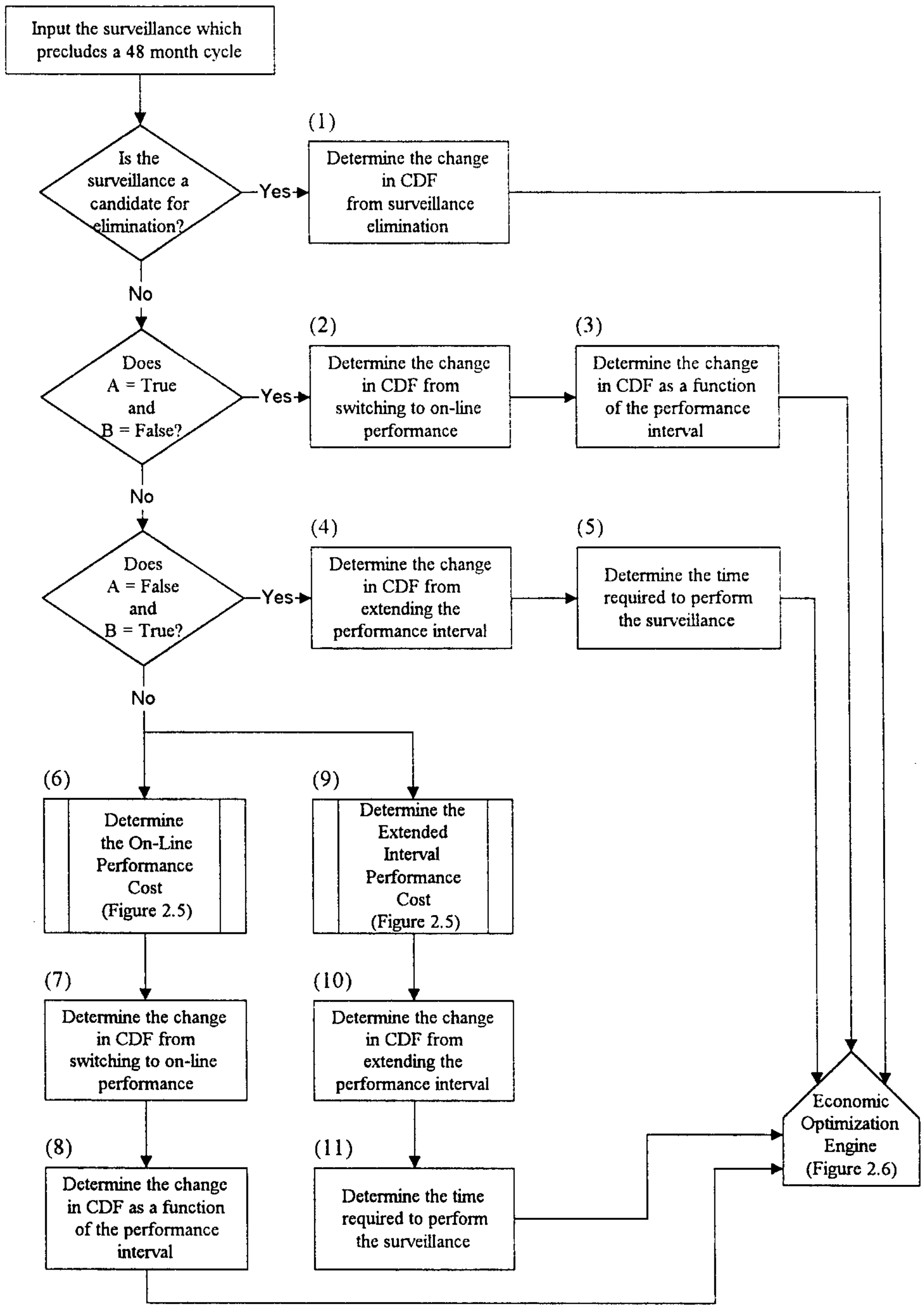


Figure 2 - 4[5]

[5] Maurer, p. 35.

becomes the critical path towards outage completion. Consequently, surveillances performed after completing core refueling are extremely expensive. Therefore, the time required to perform a surveillance during an outage must be considered by the Economic Optimization Engine to determine the combination of surveillance performance modes which will minimize the number of surveillances performed after the core has been refueled. The time required to perform A = False, B = True surveillances is a "given" variable to the Economic Optimization Engine.

(6) Determine the On-Line Performance Cost (Refer to Figure 2.5)

If a surveillance can be made compatible with an extended operating cycle by either performing it on-line or extending the performance interval, a resolution decision must be made. A key variable in this decision is the cost of performing the surveillance on-line. Several of the factors which determine the cost of performing a surveillance on-line are discussed below.

- Labor/Exposure

A surveillance which is simple to perform off-line may be extremely complex when performed at power. Extra surveillance preparation time may be required when performing a surveillance on-line because system interdependencies and contingencies must be considered. Actual surveillance performance may have to proceed at a slower than usual pace to ensure no mistakes are made which could cause a plant transient or reactor trip. Another potential drawback of on-line surveillance performance is a possible increase in radiation exposure to plant personnel . (A figure of $10,000 per man-rem is the figure used at the plant where research was conducted.) Increased surveillance performance time and increased radiation exposure increase surveillance performance costs.

- Modifications

In order to perform some surveillances on-line it may be necessary to make modifications to the existing plant configuration or additions to the plant inventory. Changes may have to be made simply to gain access (directly or

remotely) to the component or system involved in the surveillance. Redundant equipment may have to be added so that the component or system to be tested can be taken out of service while the plant is at power. On-line testing equipment may have to be added to the plant's inventory. Any changes to the plant configuration or additions to the plant inventory increase on-line performance cost.

❐ Planning

Extra planning for on-line surveillance performance including additional training of plant personnel will likely be required if a surveillance is performed on-line. Normal testing line-ups may have to be altered if a surveillance performance mode is changed from off-line to on-line. Such changes would require analysis by senior engineers. The planning and training required for on-line surveillance performance will increase the cost of the surveillance.

❐ Performance Frequency

To maintain current risk levels when an extended fuel cycle is adopted, it may be necessary to perform on-line surveillances more frequently. If the frequency of surveillance performance increases, the cost associated with that surveillance increases proportionally.

❐ Plant Capacity

To perform some surveillances on-line, a reduction in plant power may be required. For instance, some utilities perform on-line stroke testing of Main Steam Isolation Valves (MSIV's) by reducing plant power during off-peak periods. Reduction of plant power results directly in loss of revenue, although the alternative, complete shutdown to perform, may be even more expensive. Many of the surveillances which require a reduction in plant power could likely be performed simultaneously, minimizing the loss of electricity production.

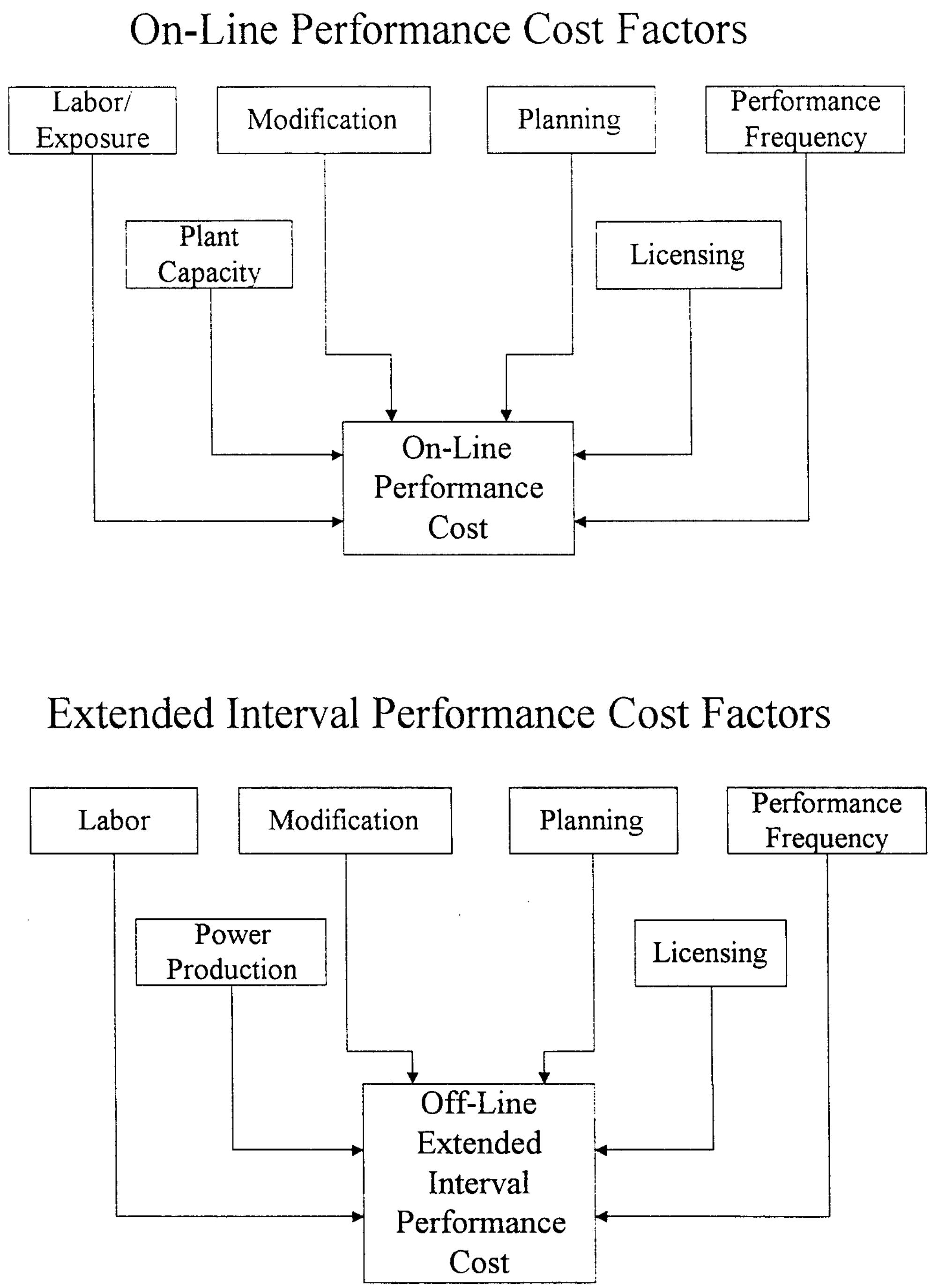


Figure 2 - 5[6]

[6] Maurer, p. 36.

❒ Licensing

Changing the performance mode of some surveillances will require approval by the appropriate regulatory authority. The mode change justification packet will require analysis by support engineering. The time spent producing the analysis will be part of the on-line performance cost.

The sum of these six cost factors yields the overall on-line surveillance performance cost. <u>This on-line surveillance performance cost for A = True, B = True surveillances is an "input" variable</u> because the alternative, extending the performance interval, is also an option. The Economic Optimization Engine will ultimately determine the performance mode.

❒ (7) Determine the changes in LPEF and CDF from switching to on-line performance

If the surveillance is performed on-line the LPEF and/or CDF may change. The change may be in either an increase (as in the case where a system or component such as a Diesel Generator is removed from service for surveillance performance) or a decrease (as in the case where the surveillance involves a system or component which is most risk significant during shutdown). <u>The changes in the LPEF and CDF from performing A = True, B = True surveillances on-line is an "input" variable</u> to the Economic Optimization Engine because the alternative, extending the performance interval, is an option. The Economic Optimization Engine will ultimately determine the performance mode.

❒ (8) Determine the changes in LPEF and CDF as a function of the on-line performance interval

If the surveillance is performed on-line, increased surveillance performance frequencies are an option. Increasing performance frequencies, as long as the surveillance itself is not a destructive examination of the component, may decrease the LPEF and/or CDF (as in the case where a preventive maintenance activity can be performed more frequently). The decrease in LPEF and/or CDF may be needed to offset the increases in

LPEF or CDF resulting from changing the performance mode or performance interval of other surveillances. The changes in LPEF and CDF as a function of the performance interval for A = True, B = True surveillances is an "input" variable to the Economic Optimization Engine because the alternative, extending the performance interval, is an option. The Economic Optimization Engine will ultimately determine the performance mode as well as the performance frequency (if on-line performance is chosen).

(9) Determine the Extended Interval Performance Cost (Refer to Figure 2.5)

If a surveillance can be made compatible with an extended operating cycle by either performing it on-line or extending the performance interval, a resolution decision must be made. A key variable in this decision is the cost of extending the surveillance interval and performing the surveillance off-line. Several of the factors which determine the cost of extending the surveillance interval and performing the surveillance off-line are discussed below.

- Labor

The amount of work conducted during refueling outages usually requires the hiring of outside contract workers. Because they are not full-time employees of the plant, these workers constitute an avoidable additional outage cost. If a surveillance must be done during the outage, extra contract workers may have to be hired to perform the work to avoid increasing the length of the outage. This will be a factor in the overall cost of extending the surveillance interval and performing the surveillance off-line.

- Modifications

Performance interval extension may require upgrading a particular component or system to ensure it remains reliable over the entire operating period. Redesigning existing components or buying, and installing new equipment is an expense which must be included in the overall off-line extended interval performance cost.

❒ Planning

Outage planning is one of the most specialized areas in the nuclear power industry. Outage planners work hard to maximize the number of surveillances performed during the core refueling period.. Extending the performance intervals of surveillances keeps them in the outage workscope and therefore increases the complexity of outage planning. The larger the outage surveillance agenda, the larger is the outage planning cost.

❒ Performance Frequency

The proper choice of performance frequency may save money. If a surveillance currently performed on a 24 month refueling interval can be extended to 48 months, surveillance performance costs will be reduced as a result of the surveillance being performed only half the number of times it is performed on a 24 month refueling interval.

❒ Power Production

Surveillances which cannot be completed in an outage before core refueling is complete become the critical path towards outage completion.. The loss of revenue due to lost electricity production would be an added cost of off-line extended interval performance. Depending on plant location, lost revenue per effective full power day can range from $500,000 to almost $1,000,000 for a plant engaged in competition.

❒ Licensing

Changing the performance interval of some surveillances will likely require approval from the appropriate regulatory authority. The interval extension justification packet will require analysis by a support engineer. The time this engineer spends producing the packet will be part of the off-line extended interval performance cost.

The sum of these six cost factors yields the overall off-line extended interval performance cost. This off-line extended interval performance cost for A = True, B = True surveillances is an "input" variable because the alternative, performing the surveillance on-line, is also an option. The Economic Optimization Engine will ultimately determine the performance mode.

❐ (10) Determine the changes in LPEF and CDF from extending the performance interval

Extending the performance intervals of surveillances performed during outages may increase the LPEF and/or CDF (as in the case where the operation of an integral safety system is checked less frequently). The changes in LPEF and CDF from surveillance performance interval extension for A = True, B = True surveillances is an "input" variable because the alternative, on-line surveillance performance, is an option. The Economic Optimization Engine will ultimately determine the performance mode.

❐ (11) Determine the time required to perform the surveillance

During a refueling outage surveillances can be performed in parallel with refueling operations without any additional increase in outage length. It is assumed that utilities already employ parallel path surveillance planning tools to help minimize outage lengths. Once the core is completely refueled, however, surveillance performance generally becomes the critical path towards outage completion. Consequently, surveillances performed after completing core refueling are extremely expensive. Therefore, the time required to perform a surveillance during an outage must be considered by the Economic Optimization Engine to determine the combination of surveillance performance modes which will minimize the number of surveillances performed after the core has been refueled. The time required to perform A = True, B = True surveillances is an "input" variable because the alternative, on-line surveillance performance, is also an option. The Economic Optimization Engine will ultimately determine the performance mode.

2.3.4. Economic Optimization Engine

The proposed Economic Optimization Engine would be a computer based tool which considers all of the "given" and "input" variables of every plant surveillance and determines the most economic surveillance performance mode combination while maintaining current risk levels. There would be two requirements on the Engine's surveillance performance mode combination conclusions. First, the proposed change in surveillance performance modes and performance intervals must be no worse than risk neutral for both the LPEF and CDF as compared to original plant cycle length. Second, the proposed changes result in the greatest economic benefit.

There would be three distinct outputs of the Engine: (as represented in Figure 2.6)

1. The optimal performance mode of all A = True, B = True surveillances

   Since both resolution options are possible, the Engine must determine which option, in combination with all other surveillance performance modes, will be the most economic route to follow.

2. The performance frequency of all A = True, B = True surveillances selected for on-line performance

   If on-line surveillance performance is selected for surveillances which also have the option of interval extension, a surveillance performance frequency must be recommended. The frequency may have to be increased in order to balance increases in LPEF and/or CDF resulting from the change of the performance mode or performance interval of other surveillances.

3. The performance frequency of all A = True, B = False surveillances

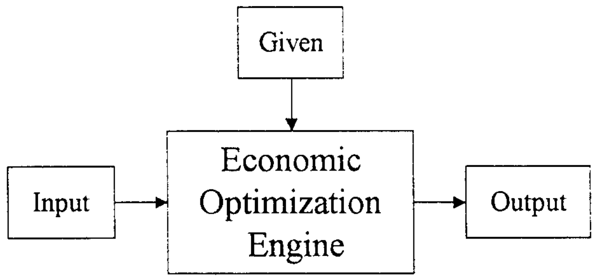
   The frequency may have to be increased in order to balance the increases in LPEF and/or CDF resulting from the change of the performance mode or performance interval of other surveillances.

2.4. Summary

Figure 2.7 summarizes the entire surveillance resolution methodology. First, a determination is made as to whether the surveillance can be performed on-line. Next, a determination is made as to whether the performance interval of the surveillance can be extended to support an extended operating cycle. The surveillances which could employ either resolution option are input into the Economic Optimization Engine. (The dotted lines represent the "given" variables role in the Engine.) The Engine determines the most economical performance mode and performance interval for these surveillances. The constraints on this combination of performance modes and intervals is that the recommended plan must be at least risk neutral for both LPEF and CDF as compared to the original surveillance plan and the recommended program yields the maximum economic benefit.

The tools necessary to determine changes in CDF as a result of changes in performance modes or performance intervals already exist in software packages such as RISKMAN developed by EPRI. Similar understanding of the role of LPE's and the LPEF on the overall surveillance structure requires significantly more study. Two other major tasks still required to make the Economic Optimization Model/Engine a reality are the development of specific quantification methods of the cost factors illustrated in Figure 2.5 and the computer-based Engine itself. These are both formidable jobs, but ones which could play a revolutionary role in reducing the operation and maintenance costs of nuclear plants by optimizing the entire plant surveillance program.

Economic Optimization Engine



GIVEN:
(1) The change in LPEF/CDF from surveillance elimination
(2) The change in LPEF/CDF from switching to on-line performance (A = True, B = False)
(3) The change in LPEF/CDF as a function of the performance interval (A = True. B = False)
(4) The change in LPEF/CDF from extending the performance interval (A = False, B = True)
(5) The time required to perform the surveillance (A = False, B = True)

INPUT:
All variables refer to surveillances with A = True and B = True
(6) The On-Line Performance Cost
(7) The change in LPEF/CDF from switching to on-line performance
(8) The change in LPEF/CDF as a function of the performance interval
(9) The Extended Interval Performance Cost
(10) The change in LPEF/CDF from extending the performance interval
(11) The time required to perform the surveillance

OUTPUT:
1. The optimal performance mode of all A = True, B = True surveillances
2. The performance frequency of all A = True, B = True surveillances selected for on-line performance
3. The performance frequency of all A = True, B = False surveillances

Figure 2 - 6[7]

[7] Maurer, p. 46.

Simplified Surveillance Resolution Flowchart

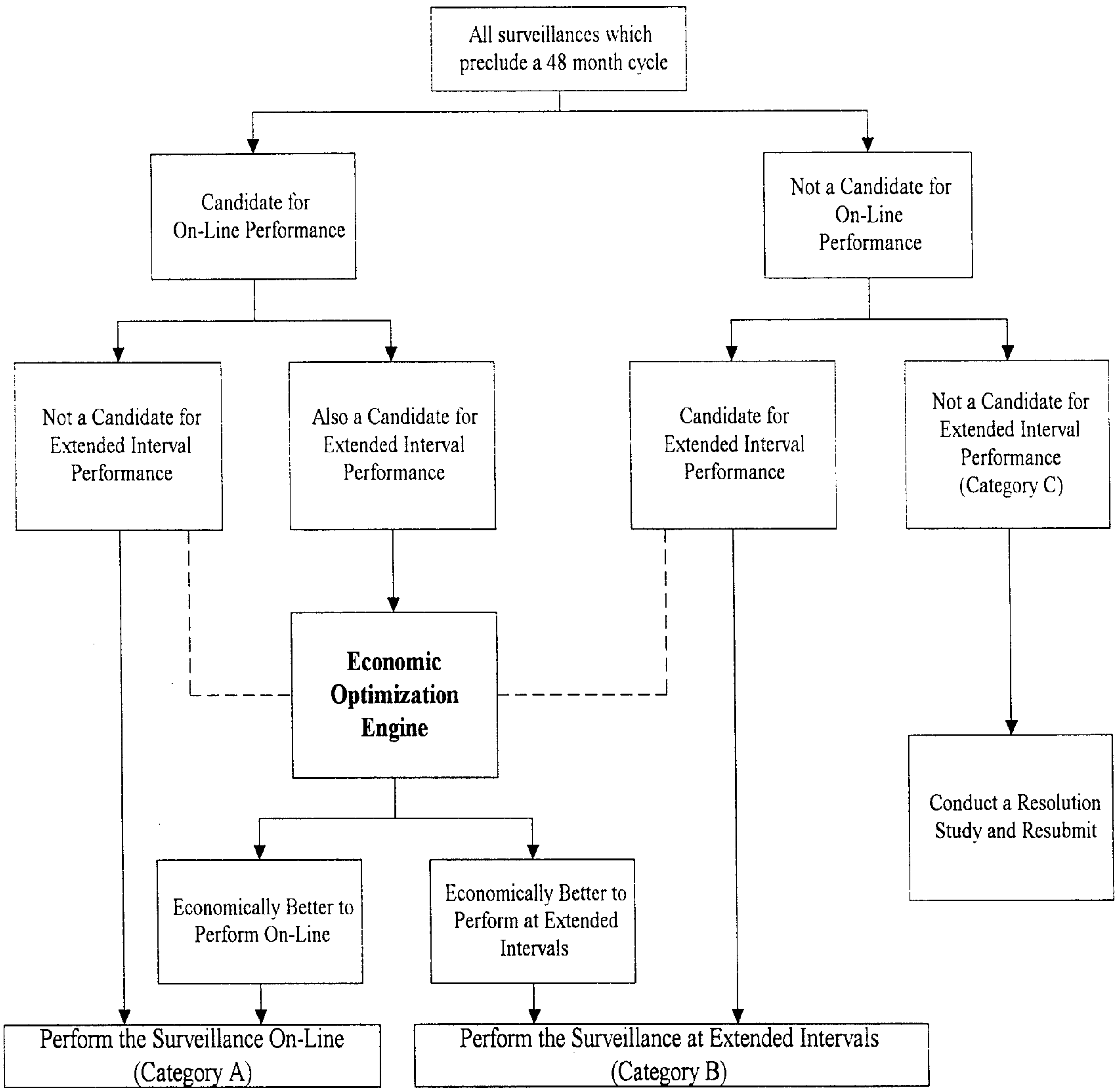


Figure 2 - 7

Chapter 3 - Surveillance Categorization

3.1 Regulatory Based Surveillances

For the purpose of this study, surveillances performed at the candidate PWR to meet technical specification requirements are considered to form the set of regulatory based surveillances that must be resolved consistent with a 48 month fuel cycle. The use of the technical specifications as the basis for the set of regulatory based surveillances provides a simple method for further classifying these surveillances. Surveillances were classified and analyzed according to their applicable technical specification section. By doing this, the analysis and results presented in this report are compatible with any Westinghouse PWR technical specifications including the improved Westinghouse Standard Technical Specifications which the Nuclear Regulatory Commission (NRC) is strongly advocating. Administrative Technical Specifications and Refueling Technical Specifications are not included in the analysis because their specific requirements were found to be independent of cycle length. Technical Requirements, which are also part of the licensing basis, but which only require onsite technical evaluations to change, were included as part of this analysis. The PWR technical specification sections which form the basis for the analysis are:

- In-Service Testing/Inspection
- Section 1 - Reactivity Control
- Section 2 - Power Distribution Limits
- Section 3 - Instrumentation
- Section 4 - Reactor Coolant System (RCS)
- Section 5 - Emergency Core Cooling Systems (ECCS)
- Section 6 - Containment
- Section 7 - Plant Systems
- Section 8 - Electrical Systems
- Technical Requirements

Surveillances whose performance satisfied more than one technical specification section were only counted one time and placed in the most applicable technical specification section for analysis. For example, reactor coolant loop flow calibrations satisfied technical requirements for both the instrumentation and reactor coolant system sections. Because the loop flow calibration requirements closely matched other instrument calibrations (temperatures, pressures, levels) found only in the instrumentation section, it was placed in the instrumentation section. Where there was no clear demarcation line, the surveillance was placed in the first applicable section. For example, Engineered Safeguards Pump and Valve Response Time Testing satisfied many technical specification requirements including those belonging to in-service testing, plant systems, instrumentation, and electrical systems sections. Because it could easily be placed in any of the above sections, the first applicable section, in-service testing was chosen.

There are 1772 individual surveillances performed to meet the requirements in the technical requirements and the technical specifications at the candidate PWR plant. These 1772 individual surveillances, currently matched to an 18 month fuel cycle, are broken down as shown in Table 3.1.

The 571 surveillances already performed on-line will continue to be performed on-line regardless of cycle length and therefore do not affect an extended cycle length. They are not be studied further in this report. However, their current performance intervals should be evaluated as part of the broader optimization strategy discussed in Chapter 2 to determine if their performance intervals are being optimized from both a safety and economic standpoint. Analysis of the 1201 remaining surveillances currently performed while shutdown forms the basis for the analysis in this chapter. Of these 1201 surveillances, 278 have performance intervals which are already compatible with a 48 month fuel cycle, 268 of which are electrical surveillances.

18 Month Cycle Regulatory Based Surveillance Breakdown

Table 3 - 1

Technical Specification Section	Total Surveillances	Number On-line	Number Off-line
In-Service Testing	229	60	169
Reactivity Control	17	12	5
Power Distribution Limits	17	16	1
Instrumentation	436	318	118
Reactor Coolant	18	8	10
ECCS	16	6	10
Containment	81	25	56
Plant Systems	51	41	10
Electrical Systems	846	32	814
Technical Requirements	61	53	8
Totals	**1772**	**571**	**1201**

A discussion of each technical specification section follows. Utilizing the methodology and criteria developed in Chapter 2 of this report, each section analyzes those surveillances currently performed shutdown which are applicable to that section, and resolves their performance consistent with a 48 month fuel cycle. A detailed discussion of the surveillances classified as Category A or B is included. Those surveillances classified as Category C surveillances are listed along with a brief discussion. A more detailed discussion of all Category C surveillances with possible engineering solutions is provided in Chapter 4. A table comparing the current 18 month surveillance performance program to the recommended surveillance performance program for a 48 month fuel cycle concludes each section.

3.1.1 In-Service Testing

3.1.1.1 Discussion

In-service testing is performed to meet the requirements of 10CFR50.55.a(g) which requires all nuclear plants to set up and maintain an in-service testing program that meets the requirements of the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section XI. The ASME code has the force of law and applies to all safety related pumps and valves which are required to perform a specific function in the safe shutdown of a reactor, maintaining the shutdown condition, or mitigating the consequences of an accident. Testing is performed to assess the operational readiness of components, and thus applies mainly to standby components. The ASME code generally requires the quarterly testing of pumps and valves, although testing during cold shutdown (Mode 5) outages is allowed if it is impractical to test quarterly during operation. Cold shutdown testing has no specified time interval for performance. If a cold shutdown condition never occurs during the course of an operating cycle, then cold shutdown testing shall be completed during the refueling outage. This means, that for top performing plants, the majority of cold shutdown testing is typically performed during refueling outages. Each utility must maintain a record showing the rationale for deferring testing to cold shutdown intervals. NRC approval is not required to classify a test as a cold shutdown test, although the records justifying the extension to cold shutdown are auditable. The ASME code also allows tests to be deferred to refueling outages if cold shutdown testing or quarterly testing is impractical. The length in months between refueling outages is defined in the plant technical specifications. These deferrals require prior NRC approval and are generally associated with testing involving safety systems that cannot practically be tested with the core or vessel head in place.

As shown in table 3.1 there are 169 surveillances associated with in-service testing that are currently performed when shutdown. These surveillances should be resolved to Categories A, B, and C as discussed in the following sections.

3.1.1.2 Category A Surveillances

3.1.1.2.1 Valve Operability Checks

There are seven surveillance valve stroke checks currently performed off-line which should be considered for on-line performance. These include stroke checks of valves in the Chemical Volume and Control (CS) system, Main Steam (MS) system, Service Water (SW) system, and the Power Operated Relief Valve (PORV) block valves. Stroke checks are performed to ensure that valves reposition within specified time limits based on design basis analysis and to trend their performance from check to check. Systems with redundant trains such as SW, or valves whose stroking will not affect system performance, such as PORV blocking valves, will not impact plant operations or safety and thus should be performed on-line. The stroke checks and timing of the Main Steam Isolation Valves (MSIV's) will require the most coordination and advance planning to perform. To perform a full stroke check of each MSIV, electrical load provided to the grid and reactor power will have to be reduced to less than 75% to ensure that each valve can be safely stroked without exceeding core power limits. Although there is little incentive to perform MSIV stroke checks on-line on an 18 month cycle, several PWR's with operating cycles of 24 months have chosen to stroke their MSIV's with the reactor on-line, performing the procedure during fall or spring in off peak evening periods when power requirements are lowest. Hence, based on industry precedent, on-line stroking of the MSIV's can be safely performed.

3.1.1.2.2 Remote Valve Position Indication

There are 18 remote valve position indication surveillances currently performed off-line which can be performed with the plant on-line. Remote valve position indication checks are performed to ensure that the remote position indications of valves in both the open and closed positions match the actual local position of the valves. The position indication lights are also often used as a reference when checking the stroke times of valves. Typically, remote valve position indication checks are done concurrently with

stroke checks of the valve. The remote valve position indication checks which can be placed in Category A all involve systems where the valves are currently stroked quarterly on-line to meet IST stroke check requirements. All the valves are accessible at power and thus the valve position indication can be checked at any time as part of the quarterly stroke checks.

3.1.1.2.3 Relief Valves

There are 20 relief valve surveillances covering 33 individual relief valves currently tested off-line which can be tested with the plant at power. These relief valves are located in the diesel, safety injection, core building spray, residual heat removal, demineralized water, and waste liquid drain systems. Relief valve testing is performed in accordance with the "Operations and Maintenance of Nuclear Power Plants, ASME/ANSI (American National Standards Institute), OM-1987" Chapter 1. Utilities have the option of testing the relief in-place or bench testing a spare relief valve in order to confirm its operability and then performing a simple one for one swap of the relief in question. With the exception of Main Steam Safety Valves, most utilities opt to perform swaps with bench tested spares because it places the individual system out of service for shorter periods of time and guarantees that the replacement relief has already passed its lift test. Because a system is inoperable while performing relief valve swaps, on-line swaps cannot be performed on systems which are required to be active with the reactor on-line such as reactor coolant (RC) or component cooling (CC). Passive systems, however, such as relief valves for the diesel generators can be replaced by tagging the component out of service to ensure inoperability during relief swaps. Relief valve swaps take a minimum amount of time and should be able to be performed well within the system LCO time limits with proper advance planning. The minimum technical specification LCO time for the systems listed above is 72 hours for containment building spray. Even assuming that a utility will not voluntarily exceed 50% of a technical specification LCO, that leaves 36 hours in which to perform a relief valve swap. This policy is reasonable and should be pursued.

3.1.1.2.4 Functional Testing

There are 41 functional tests currently performed off-line which can be performed with the reactor on-line. System functional tests are detailed inspections of each system required by the ASME code to check the integrity of welds, piping, and valves System engineers at the candidate PWR estimate that 80-90% of each system is already checked with the reactor on-line and that the remaining 10-20% of the inspections could be performed with the reactor on-line with proper planning. For those portions of the systems which are inaccessible with the reactor on-line, enough inspection points should exist from accessible portions of the system to make a sound technical decision as to whether those small portions which are inaccessible could safely be done at 48 month intervals. If there are specific concerns about waiting that long between inspections, remote cameras or robotic inspection tools could provide the needed information.

3.1.1.2.5 Pump Operability Checks

The turbine driven emergency feedwater (EFW) pump operability checks currently performed off-line can be performed with the plant on-line. Pump operability checks are performed to check that pump parameters including pump head, inlet pressure, differential pressure, and vibration are within specification. While the turbine driven EFW pump cannot be aligned to the steam generators with the plant on-line because its source of suction water is too cold and could cause thermal shock to the steam generators, the turbine driven EFW pump can be aligned in the recirculation mode to the Refueling Water Storage Tank (RWST) to confirm the necessary pump data.

3.1.1.3 Category B Surveillances

3.1.1.3.1 Valve Operability Checks

There are 17 valve stroke check surveillances which include over 60 individual air operated and motor operated valves currently performed while shutdown which could

safely be performed at 48 month intervals. These valves are currently stroked at 36 month intervals. Based on a station evaluation of motor operated valves in response to Generic Letter 89-10 (Safety-Related Motor-Operated Valve Testing and Surveillance), only seven of 122 motor operated valves were recommended for testing intervals (36 months) less than 48 months. The remaining valves had recommended maintenance intervals of 72 months or more and are therefore compatible with an extended fuel cycle. The evaluation combined the risk significance of the valve, differential pressure conditions across the valve during demand, and whether the valve was required to reposition in case of a design basis accident. Based on this review, only those valves which combined a high risk level with a high differential pressure across the valve were recommended for maintenance intervals less than 48 months[8]. High differential pressure valves have a significantly higher failure rate than valves with low differential pressures. The failure mechanism of concern over extended intervals is binding of the valve caused by corrosion/wear product buildup or lubrication breakdown. The lubrication can be inspected and replenished at frequent intervals. Additionally, most of the valves in this group are large butterfly or gate valves which exhibit minimal throttling characteristics over the first half of valve disc travel. This valve characteristic allows the partial throttling of these valves without interruption of flow to the system. Partial valve strokes at more frequent intervals should eliminate any valve binding concerns. Additionally, if the motor is sized correctly for the valve, overtorquing of the valve or lack of power from the motor to move the valve to its demand position should not be a concern. Utilities which do not partially cycle their motor operated and air operated valves to eliminate valve binding should consider adding that maintenance practice as part of any long-term surveillance strategy.

3.1.1.3.2 Check Valves

There are 28 check valve surveillances which include a total of 106 check valves currently performed shutdown which could safely be performed at 48 month intervals.

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[8] O'Regan, Pat J., Engineering Evaluation 93-44. "Evaluation of the Candidate PWR Response to Generic Letter 89-10 (Safety-Related Motor-Operated Valve Testing and Surveillance)", September 1993, p.4.

Check valve surveillances are intended to confirm check valve operability through either visual inspection, radiographic examination, full flow checks through the valve, or checks of back seat tightness. Check valves are relatively simple in design, with no power requirements and very few moving parts. As long as the pins holding the valve disc in place do not bind as the result of corrosion products or other foreign material buildup the valve is likely to perform its intended function. A review of plant material history shows that the check valves are very reliable. System engineers believe that these 106 check valves would easily support a 48 month inspection interval. Similar to the issues surrounding motor operated valves, many of these check valves can be partially stroked using alternate flow paths. Although this will not provide a full flow check, it will exercise the check valve sufficiently to prevent the buildup of corrosion products on the valve swing surfaces. In addition to the check valve data available at the candidate PWR, Oak Ridge National Laboratories has been maintaining a Nuclear Industry Check Valve (NIC) database since 1991 which could also be used to support interval extension justifications.

3.1.1.3.3 Remote Valve Position Indication

There are 15 remote valve position indication surveillances, including over 60 individual valves, that are currently performed with the plant shutdown which can safely be performed at 48 month intervals. The ASME code requires that valve position indication checks be performed every two years. The valve position indication check confirms that the indicated position matches the actual valve position in both the open and closed positions. The 15 remote valve position indication surveillances listed in this section are typically performed in conjunction with the stroking of the motor and air operated valves discussed in section 3.1.1.3.1. Since analysis as shown that these valves can be safely stroked every 48 months, the valve position indication checks should also be deferred until the valve stroking. Partial verification that the valve position indication system is functioning properly can be obtained by checking that the valve position indication continues to match the normal position of the valve and that the position

changes to mid-position (no open or closed light) during the recommended frequent partial valve stroke checks.

3.1.1.3.4 Leak Checks

There are four reactor coolant leak rate tests performed as part of the in-service testing program which can safely be performed at 48 month intervals. These valves are subject to the same 10CFR50 Appendix J requirements as containment isolation valves. After two successive leak tests their performance intervals could be extended to up to 10 years.

3.1.1.3.5 Pump Operability Checks

The three auxiliary feedwater pumps have pump operability checks currently performed shutdown which could safely be performed at 48 month intervals. These three pumps, the turbine driven EFW, electric driven EFW, and the Startup Feed Pump (SUFP), can all be run in the recirculation mode to confirm that most of their key operating parameters are within specification. The only requirement that cannot be fulfilled on-line is proving that each pump can provide rated capacity to the steam generators. The SUFP is only operated to provide water to steam generators in hot standby, wet lay-up, or with reactor power less than three percent. All major pump parameters can be confirmed to be within specification with the exception of sending water directly to the steam generators. The EFW pumps are used as backups to the Main Feed Pumps following a scram in order to ensure that the steam generators, which are the primary decay heat removal source, continue to receive water. Because the suction water source for the EFW pumps is too cold to align to the steam generators with the plant on the line due to thermal shock concerns, the EFW pumps should be confirmed operable by combining past performance history with pump data available from running the pumps in the recirculation mode or against shutoff head with the discharge valves shut. This should provide enough data to justify deferring aligning the EFW pumps to the steam generators for capacity checks to once every 48 months.

3.1.1.4 Category C Surveillances

Chapter 4 provides a more detailed discussion of each of the Category C surveillances listed in sections 3.1.1.4.1 through 3.1.1.4.3.

3.1.1.4.1 Relief Valves

There are 12 relief valve surveillances, which include a total of 38 individual relief valves, currently performed shutdown at intervals less than 48 which cannot be performed on line, and are unlikely to be extendible to 48 months. These 38 valves include the three pressurizer relief valves which are Class 1 relief valves (primary pressure boundary) and 35 Class 2 relief valves (containment pressure boundary).

3.1.1.4.2 Diesel Generator Operability and Engineered Safeguards Pump and Valve Response Time Testing

There are two integrated diesel generator operability and engineered safeguards pump and valve response time tests (one for each train) currently performed shutdown at 18 month intervals which cannot be performed on line, and are unlikely to be extendible to 48 months.

3.1.1.4.3 Valve Operability Checks

There is one valve stroke and time check surveillance currently performed with the plant shutdown at 18 month intervals which cannot be performed on line, and is unlikely to be extendible to 48 months. This surveillance involves the stroke check of three motor operated valves evaluated as combining the highest risk level and the highest valve differential pressure during operation. These valves are currently recommended for performance checks every 36 months and further study is required to justify their extension to 48 months.

3.1.1.5 Summary of In-Service Testing Surveillances

Table 3.2 compares the current 18 month surveillance program for in-service testing to the recommended surveillance program for a 48 month fuel cycle based on the justifications provided above.

In-Service Testing Surveillance Summary

Table 3 - 2

Cycle Length	Category A	Category B	Category C
18 Months	60	169	----
48 Months	147	67	15

3.1.2 Reactivity Control

3.1.2.1 Category A Surveillances

There is one reactivity control surveillance currently performed off-line which should be considered for on-line performance. The emergency boration flow test is performed to ensure that the two boric acid pumps supply a minimum of 30 gpm to the reactor coolant system via the suction of the coolant charging pumps. The test is currently performed off-line because planners do not want boric acid injected into the reactor coolant system with the reactor on the line. However, this assumes that the boric acid pumps must take a suction on the boric acid tanks to achieve their 30 gpm check. Inspection of the system reveals that the boric acid pumps can also be aligned to take a suction from a 1620 gallon boric acid batch add tank. The batch add tank serves as a mixing point for boric acid and uses the same boric acid pumps to fill the boric acid tanks to normal levels. For the purposes of this test, the batch add tank could be filled with demineralized water and the boric acid pumps aligned to take a suction from the batch add tank for the flow check. This has the added advantage of keeping the normal boric acid tanks filled during testing in case they are needed for an actual emergency. In the unlikely event that they were needed to inject boric acid into the reactor coolant system, it would

be a simple matter of repositioning two valves to realign the suction of the boric acid pump back to its associated boric acid tank. The redundancy of the system (there are two boric acid pumps and boric acid tanks) also means that during the surveillance at least half the system would be available to fulfill its normal function.

3.1.2.2 Category B Surveillances

Four surveillances currently performed shutdown can safely be performed at 48 month intervals. One of the surveillances is performed weekly as part of the normal refueling outage surveillance package and is independent of cycle length.

Control and shutdown rod drop testing is currently done at 18 month intervals following refueling to guarantee that the control rods have an unimpeded path to the bottom of the core and that maximum drop times are consistent with the assumed drop times used in the plant safety analysis. While the current plant technical specifications call for performance of rod drop testing every 18 months following refueling, the NRC's recent Improved Standard Technical Specifications (ISTS) only require rod drop testing following vessel head removal which is a subtle but significant change in wording. Since the vessel head will not be removed between refueling periods, rod drop testing can safely be performed at 48 month intervals. Core designers should continue to evaluate the possibility of fuel swelling over a 48 month cycle to ensure that rod channel clearances would not inhibit rod motion and cause rod drop times to exceed design basis limits.

Rod position indication checks are required every 18 months. The purpose of the rod position checks is to confirm that the highly accurate (+/- 1 step or +/-5/8 inch) demand position for each rod, generated based on the amount of time a rod is withdrawn or inserted, matches, within specified limits, the indicated rod position generated by a series of coils spaced along each hollow rod tube which produce an inductive analog signal. The demand position, although theoretically more accurate, will not identify if a rod is stuck in the channel during insertion or withdrawal. The purpose of the rod position check is to ensure that the two indication systems match over the entire range of rod motion to ensure that a stuck rod would be identified. Once a plant is at power, the

control rods are fully withdrawn and remain fully withdrawn with the long term reactivity balance maintained by changing core boron level. As long as the rods are maintained fully withdrawn the relationship between the demand position and the indicated position remains unchanged regardless of the cycle length. If however, the reactor had to be shutdown after more than 18 months since the performance of the last rod position checks, then these checks would have to be performed prior to reactor startup. In essence, the scheduling of rod position checks could conform to a 48 month cycle. However, the rod position checks would be required to be on a hot list for completion.

3.1.2.3 Category C Surveillances

There are no category C surveillances for this technical specification.

3.1.2.4 Summary of Reactivity Control Surveillances

Table 3.3 compares the current 18 month surveillance program for reactivity control surveillances to the recommended surveillance program for a 48 month fuel cycle based on the justifications provided above.

Reactivity Control Surveillance Summary

Table 3 - 3

Cycle Length	Category A	Category B	Category C
18 Months	12	5	----
48 Months	13	4	0

3.1.3 Power Distribution Limits

3.1.3.1 Category A Surveillances

The reactor coolant system flow measurement surveillance currently performed during refueling outages can be performed with the reactor on-line. The measurement is

performed via a precision heat balance. The procedure for completion of the surveillance has no mode requirements for performance.

3.1.3.2 Category B Surveillances

There are not category B surveillances for this technical specification.

3.1.3.3 Category C Surveillances

There are no category C surveillances for this technical specification.

3.1.3.4 Summary of Power Distribution Surveillances

Table 3.4 compares the current 18 month surveillance program for power distribution surveillances to the recommended surveillance program for a 48 month fuel cycle based on the justifications provided above.

Power Distribution Surveillance Summary

Table 3 - 4

Cycle Length	Category A	Category B	Category C
18 Months	16	1	----
48 Months	17	0	0

3.1.4 Instrumentation

3.1.4.1 Category A Surveillances

There are 72 instrumentation surveillances currently performed while shutdown which should be considered for on-line performance. Thirty-six of these surveillances involve instrument calibration checks and 36 involve time response testing.

The instrument calibrations include the following instruments:

Reactor Trip System Instrumentation

Loop Flow - 12 surveillances

Pressurizer Level - 3 surveillances

Power Range Nuclear Instrument (PRNI) - 4 surveillances

Pressurizer Pressure - 4 surveillances

Temperature detectors - 2 surveillances

Turbine Impulse Pressure Calibration - 2 surveillances

Turbine Stop Valve Pressure Switch Calibration - 2 surveillances

Engineered Safety Feature Actuation System (ESFAS) Instrumentation

Containment Pressure - 3 surveillances

Post Accident Monitoring (PAM) Instrumentation

Excore flux monitors - 2 surveillances

Reactor Vessel Level Instrumentation - 2 surveillances

All the instruments listed above are accessible with the reactor on-line. Additionally, for Reactor Trip System instruments and ESFAS instruments the ISTS allow a channel to be bypassed for up to four hours for surveillance testing. System engineers confirm that instrument calibrations can easily be performed in this time frame. One channel of PAM instrumentation may be bypassed for up to 30 days, allowing easy on-line calibrations.

In the past, concerns over reactor trips caused by operator error or other spurious channel trips during the performance of instrument calibrations led many utilities to defer all reactor trip system instrument calibrations to shutdown periods. A relatively inexpensive, but key addition, to the Reactor Trip System now allows on-line performance of calibrations with significantly less risk of shutdown from either operator error or spurious channel trips. The original design of many Westinghouse protective systems called for a reactor trip if a trip signal was received from at least two of four instrument channels with inputs to the reactor protective system. In the original design, an instrument channel was placed in trip to perform on-line tests or calibrations. This meant that a trip

signal from only one of the three remaining channels was sufficient to cause a reactor trip. This extra trip signal could originate from an actual signal, spurious signal, or by operator error if a wrong switch or dial were adjusted during the calibration procedure. This system was overly conservative and did not allow for one spurious trip signal as the system was originally designed. To correct this problem, the design was changed by installation of a Bypass Test Instrument (BTI). With the BTI, an instrument is bypassed and not placed in trip to perform testing or calibration. While in bypass, the instrument provides no inputs to the protective system which is now configured in a two of three logic required for a trip. With the BTI installed, safe on-line testing can occur with a very high degree of confidence.

The 36 time response surveillances are performed to ensure that the time interval from a given limiting plant condition until the loop produces a corresponding instrument signal to the protective system is within specification. These tests are performed at 54 to 72 month intervals depending on the instrument and can safely be performed on-line because of the redundancy and coincidence requirements for each instrument. Their current performance interval does not preclude a 48 month fuel cycle, but they should be considered for on-line performance.

3.1.4.2 Category B Surveillances

There are 42 instrumentation surveillances currently performed shutdown which can safely be performed at 48 month intervals.

Twenty four of the surveillances are inspections of main turbine valves including high pressure turbine stop valves, high pressure turbine control valves, and low pressure turbine control valves. These valves are currently disassembled, inspected, and reassembled at approximately 40 month intervals. Material history records indicate that the valves inspections could be performed at 48 months intervals.

There are 12 calibrations of RCP and 4.16 KV breaker undervoltage and underfrequency relays. The calibrations involve the testing of two sets of two relays which are responsible for initiating undervoltage or underfrequency trip signals to the

Solid State Protection System (SSPS). The signals warn of an impending loss of flow so that the SSPS can trip the reactor on an anticipatory loss of flow and prevent a possible sequential loss of flow. Both sets of relays must send a signal to the SSPS to initiate a trip signal. One of the relays can be bypassed similar to the BTI system described in section 3.1.4.1 and tested on-line quarterly. The other relay, an Agastat time delay relay, cannot be tested on-line because its time delay design cannot be bypassed. Testing therefore inserts one of the two trip signals necessary to initiate a reactor trip, leaving the plant in an undesirable one of one logic required for a reactor trip. System engineers state, and material records confirm, that the failure rates of both these types of relays is so small that their tests are extendible to 48 month intervals. As a second option, redesign of the Agastat relay device to allow on-line bypass testing would permit these 12 calibration surveillances to be performed on-line.

Reactor Trip System switchgear inspections and post refueling pre startup Reactor Trip Breaker surveillances can safely be performed at 48 month intervals.

Solid State Protective System (SSPS) time response testing is currently performed shutdown at 36 month intervals. The highly reliable components of this system can safely be tested at 48 month intervals.

The two Source Range Nuclear Instrument (SRNI) calibrations can only be performed while shutdown. Since they provide an important safety monitoring function during reactor startups they should continue to be calibrated at 18 month intervals prior to a reactor startup. However, once reactor power is raised into the intermediate range the SRNI's are turned off to prevent detector damage and thus have no function when the reactor is at power. SRNI calibrations can therefore be deferred past 18 months as long as the reactor stays at power. After 18 months the SRNI's should be placed on a hot list for calibration if the reactor is shutdown before a scheduled refueling outage. Calibration should occur before reactor startup is begun.

3.1.4.3 Category C Surveillances

There are two surveillances currently performed while shutdown at 18 month intervals which cannot be performed on line, and which are unlikely to be extendible to 48 months. The two surveillances are identical (one for each train) and verify that the automatic safety injection, containment building spray, and containment building air systems actuate within allowable time limits upon receipt of a test signal. The tests also verify that manual alarms for these systems function correctly. These tests are typically performed in conjunction with the Diesel Generator Operability and Engineered Safeguards Pump and Valve Response Time Testing described in section 3.1.1.4.2. Chapter 4 provides a more detailed discussion of this Category C surveillance.

3.1.4.4 Summary of Instrumentation Surveillances

Table 3.5 compares the current 18 month surveillance program for instrumentation surveillances to the recommended surveillance program for a 48 month fuel cycle based on the justifications provided above.

Instrumentation Surveillance Summary

Table 3 - 5

Cycle Length	Category A	Category B	Category C
18 Months	318	118	----
48 Months	390	44	2

3.1.5 Reactor Coolant System

3.1.5.1 Category A Surveillances

There are five surveillances currently performed shutdown which should be considered for on-line performance. These include two incore instrument sump level calibrations, pressurizer heater kilowatt check, pressurizer pressure control loop calibration, and pressurizer relief tank temperature calibration. All the instruments are accessible during reactor operation and there are no mode restrictions in the procedures for performing the surveillances.

3.1.5.2 Category B Surveillances

There are four surveillances currently performed shutdown which can safely be performed at 48 month intervals. Two of the surveillances are performed to meet requirements when in a refueling outage and are therefore independent of cycle length.

The reactor coolant pump flywheel bore and keyway are currently ultrasonically inspected for volumetric expansion in the areas of highest stress concentration every 36 months. Material history records indicate and discussions with system engineers and pump vendors confirm that this test could safely be performed at 48 month intervals. A complete surface examination of all exposed reactor coolant pump surfaces and a complete ultrasonic volumetric examination is conducted at approximately 10 year intervals and does not impact on a 48 month operating cycle.

3.1.5.3 Category C Surveillances

Steam generator eddy current testing is currently performed shutdown at 18-24 month intervals. This surveillance cannot be performed on line, and is unlikely to be extendible to 48 months. Chapter 4 provides a more detailed discussion of this Category C surveillance.

3.1.5.4 Summary of Reactor Coolant System Surveillances

Table 3.6 compares the current 18 month surveillance program for reactor coolant system surveillances to the recommended surveillance program for a 48 month fuel cycle based on the justifications provided above.

Reactor Coolant System Surveillance Summary

Table 3 - 6

Cycle Length	Category A	Category B	Category C
18 Months	8	10	----
48 Months	13	4	1

3.1.6 Emergency Core Cooling Systems

3.1.6.1 Category A Surveillances

There are three surveillances currently performed off-line which should be considered for on-line performance.

The Safety Injection (SI) accumulator outlet valve P-11 surveillance demonstrates the ability of the four SI accumulator outlet valves to open automatically when the reactor coolant pressure exceeds the P-11 setpoint. The P-11 setpoint is a combination of plant signals whose simultaneous occurrence is considered to be indication of a large loss of coolant accident. The four motor operated valves associated with this test have a low risk significance and a low differential pressure across the valve during design operation. Based on this, they are recommended for testing at intervals greater than every 10-15 years[9]. Although valve operation cannot occur with the plant on-line, the P-11 setpoint can still be tested by opening the four breakers feeding these motor operated valves and installing test gear to show that a valve reposition signal reaches each SI accumulator

[9] O'Regan, Table 3.

valve upon insertion of a simulated P-11 setpoint. The test could easily be conducted within an approved LCO.

The RHR/RC suction valve interlock verification surveillance is performed to ensure that the two RHR pump double suction valves which isolate the high pressure reactor coolant system hot leg from the low pressure RHR piping will not open if the reactor coolant pressure is 365 psig or greater. The purpose of the interlock is to prevent damage to the RHR piping and a possible LOCA. The RHR is a low pressure decay heat removal system principally designed for use when shutdown. Removal of one train at a time from service for testing with the reactor on-line involves lower risk than if the test was performed while shutdown. To ensure that high pressure water is not inadvertently injected into the low pressure RHR suction piping should the test fail, the breakers to the RHR suction valves motor operators should be opened and test gear installed to confirm that the interlock functions properly when attempts are made to open the valve remotely with the reactor coolant system pressure greater than 365 psig.

The containment and containment spray recirculation sump surveillance has no mode restrictions associated with its performance and can be performed with the plant on-line. The sump is accessible during reactor operations, but additional radiological controls might be required to safely perform the surveillance.

3.1.6.2 Category B Surveillances

There are five ECCS surveillances currently performed off-line which can be performed at 48 month intervals. Four of the five surveillances are performed weekly only when shutdown and are independent of cycle length. The ECCS throttle valve verification confirms that 12 throttle valves in the SI system have not been moved from their preset positions. These valves are inaccessible during reactor operation and thus can only be inspected or operated during shutdown periods. The surveillance performance interval is therefore independent of cycle length.

3.1.6.3 Category C Surveillances

There are two identical surveillances, one for each ECCS train, currently performed off-line at 18 month intervals which cannot be performed on line, and are unlikely to be extendible to 48 months. This test which is similar in nature to the ESFAS integrated test included in section 3.1.4.3, tests that various ECCS systems will realign within specified time limits upon receipt of a SI signal. This includes initiation of feedwater isolation, diesel generator start, containment isolation, containment ventilation system isolation, and primary component cooling water system (PCC) realignment. Chapter 4 provides a more detailed discussion of this Category C surveillance.

3.1.6.4 Summary of ECCS Surveillances

Table 3.7 compares the current 18 month surveillance program for emergency core cooling system surveillances to the recommended surveillance program for a 48 month fuel cycle based on the justifications provided above.

ECCS Surveillance Summary

Table 3 - 7

Cycle Length	Category A	Category B	Category C
18 Months	6	10	----
48 Months	9	5	2

3.1.7 Containment Systems

3.1.7.1 Discussion

The move towards a performance based containment leak testing program, approved in the latest changes to 10CFR50 Appendix J, has made the containment testing program compatible with a 48 month fuel cycle. Integrated Leak Rate Tests (Type A)

may be performed at up to 10 year intervals based on past performance results. Penetration Leak Rate Tests (Type B), and Valve Seat Leakage Tests (Type C) may be performed at up to 5 year intervals based on past performance results.

Leak rate tests are required to be performed with air to simulate the worst case design conditions which the valves, piping, or penetrations would be subject to in the event of a release of radioactivity to the containment. For this reason, it is very difficult to perform leak rate tests of valves in fluid systems with the reactor on-line because the system must be drained prior to leak rate testing. Consequently, most of the fluid system leak rate tests are performed during outages when the operations department can drain the system to support leak rate testing and other required maintenance.

3.1.7.2 Category A Surveillances

There are 36 containment surveillances currently performed while shutdown which should be considered for on-line performance. All the surveillances involve gas systems, systems which can be drained on-line, or personnel hatches which are accessible during plant operation. These include Waste Liquid Drains (WLD), Containment Air Handling (CAH), Combustible Gas Control (CGC), Fire Protection (FP), Nitrogen Gas (NG), and Containment Building Spray (CBS).

3.1.7.3 Category B Surveillances

There are 20 containment surveillances currently performed shutdown at 18 month intervals whose performance intervals are extendible to 48 months. These 20 surveillances include the Reactor Containment Integrated Leak Rate Test and 19 Type C leak rate tests performed on systems including: Reactor Coolant (RC), Component Cooling (CC), Chemical Volume and Control (CS), Safety Injection (SI), Demineralized Water (DM), Reactor Makeup Water (RMW), and Spent Fuel Handling (SF). Some of these fluid systems could be drained to conduct air drop tests with the reactor on-line. However, because the valve performance history will allow the performance interval to be extended

to 48 months, the added work required to perform the testing on-line makes it an uneconomical choice.

3.1.7.4 Category C Surveillances

There are no Category C containment surveillances.

3.1.7.5 Summary of Containment Surveillances

Table 3.8 compares the current 18 month surveillance program for containment surveillances to the recommended surveillance program for a 48 month fuel cycle based on the justifications provided above.

Containment Surveillance Summary

Table 3 - 8

Cycle Length	Category A	Category B	Category C
18 Months	25	56	----
48 Months	61	20	0

3.1.8 Plant Systems

3.1.8.1 Category A Surveillances

All 10 of the plant system surveillances currently performed off-line should be considered for on-line performance.

Eight of the surveillances involve calibrations of the two emergency feedwater flow indication and auto valve closure instruments associated with each of the four steam generators. The flow indicators provide a signal which isolates the emergency feedwater piping in the event of a feedwater rupture. During instrument calibration this signal is unavailable. However, there are two valves and two instruments on each loop and the

redundant instrument is still available to provide an isolation signal if required. Calibration of the instruments, one at a time could easily be accomplished during a LCO.

Both the turbine driven emergency feedwater (EFW) pump and the startup feedwater pump (SUFP) can be tested on-line. The surveillance for the turbine driven EFW pump involves verifying that steam isolation valves to the pump turbine reposition and that the pump starts upon a loss of feedwater flow signal. The test is currently performed during cold shutdown because of a desire to avoid putting cold water from the turbine EFW pump into the steam generators with the reactor plant hot. However, the purpose of this surveillance is only to test whether the pump actually starts and not whether water flows to the steam generators. The EFW pump capacity checks to the steam generator are performed as part of a separate in-service testing surveillance described in section 3.1.1.3.5. Since double valve isolation is available between the turbine EFW pump and the steam generator, the test can be safely conducted during an LCO.

The SUFP surveillance is a timed test to ensure that operators can manually switch the SUFP power supply to an emergency source and manually align the SUFP to the steam generators within 30 minutes. The surveillance is performed to show that operators can avoid steam generator dryout conditions in the event the motor driven EFW pump is lost with the plant shutdown but still hot. The entire surveillance can be safely performed on-line during an LCO while maintaining double valve protection between the SUFP and the steam generators.

3.1.8.2 Category B Surveillances

There are no plant system surveillances which are recommended for off-line performance at 48 month intervals.

3.1.8.3 Category C Surveillances

There are no Category C plant system surveillances.

3.1.8.4 Summary of Plant Systems Surveillances

Table 3.9 compares the current 18 month surveillance program for plant system surveillances to the recommended surveillance program for a 48 month fuel cycle based on the justifications provided above.

Plant Systems Surveillance Summary

Table 3 - 9

Cycle Length	Category A	Category B	Category C
18 Months	41	10	----
48 Months	51	0	0

3.1.9 Electrical Systems

3.1.9.1 Discussion

Electrical system surveillances make up by far the largest portion of individual technical specification surveillances (about 48%). The vast majority of these surveillances involve breaker inspections, calibrations, or part replacements which are currently performed shutdown at 60 month intervals. With the current fuel cycle of 18 months, this means that approximately 1/3 of the shutdown surveillances are performed during each outage to level the workload. However, if the fuel cycle was extended to 48 months, utilities would have to make a choice. They would either have to significantly increase their electrical surveillance workscope during outages (a threefold increase) or perform more of the surveillances with the reactor on-line. System engineers confirmed that most of the 60 month surveillances could be performed on-line, but that planning and execution of the surveillances would be more difficult. Utilities will have to weigh the costs of performing the majority of electrical surveillances on-line versus either extending outage lengths or incurring extra labor costs to complete all the electrical surveillances in the current outage time frame.

3.1.9.1 Category A Surveillances

There are 792 electrical surveillances currently performed while shutdown which should be considered for on-line performance. Of these surveillances, 787 deal directly with breakers including penetration protection checks, unitized starter checks, molded case circuit breaker inspections, thermal overload relay calibrations, and thermal overload relay replacements. For each of these 787 surveillances the breaker's function and its electrical accessibility will have to be analyzed to determine if it can be performed on-line. Because it was too time consuming and not of significant generic value, each of the 787 breaker surveillances were not checked to confirm that they could be performed on-line. Rather, system engineer interviews were relied upon to confirm that the vast majority of these breaker surveillances could be performed on-line. The breaker surveillances which cannot be performed on-line have performance intervals of 60 months and are therefore already compatible with performance during refueling outages at 48 months.

Diesel Generator surveillances including periodic inspections, fuel pump flow checks, and 24 hour load tests can be performed on-line within a LCO. The technical specifications allow up to a seven day LCO with one diesel removed from service. Many utilities have gotten NRC permission to extend the length of this LCO to 14 days by adding an additional dedicated emergency power source such as a mobile diesel generator or a hydro-electric tie line during periods when one of the on-site diesels is removed from service for maintenance. A mobile generator would be cost effective if used by a utility which owns several plants in close proximity to each other. Use of the mobile generator to support site diesel generator maintenance could be coordinated within a utility to maximize use of the mobile generator and prevent having to purchase one generator for each plant within the utility chain.

As an important aside, even if on-line performance for diesel inspections is chosen, it is my opinion that an 18 month open and inspect interval is excessive and may result in more problems than it solves. Diesel generators are prime candidates for performance based maintenance programs. This includes the use of advanced on-line monitoring techniques such as lube oil, thermographic, and vibration analysis. Additionally, detailed trend analyses data are available following quarterly and 18 month full load tests which

should be used to confirm proper performance. Serious consideration should be given to extending the performance interval of diesel inspections to at least 36 months between each open and inspect surveillance.

3.1.9.2 Category B Surveillances

There are 22 electrical surveillances currently performed shutdown which can be performed at 48 month intervals. Five of these surveillances are performed solely to meet outage requirements and are independent of cycle length. Three of the surveillances, two Fuel Oil Service Tank cleanings, and a Diesel Generator simultaneous start test, have 10 year performance intervals and can be scheduled for performance every other outage.

There are ten breaker overcurrent relay checks including the four RCP breakers and the EFW pump breaker which can be performed at 48 month intervals. Material history records and system engineer consultation confirm that these relays are highly reliable and would allow testing at extended intervals.

The two emergency power sequencer checks confirm that, in the event of a major casualty where electrical power is lost, the diesel generators are sequentially loaded with safety components. The safety components are loaded sequentially to ensure that the most important components are available first, and to prevent dragging the diesel off line from the simultaneous start of all vital safety loads. The sequencing is coordinated through the Solid State Protection System (SSPS). With the exception of actually loading the diesel, all the logic cards and relays can be checked on a more frequent basis with the reactor on-line to confirm that the system remains functional. Diesel generator load testing is performed often enough to confirm that the diesel generator can handle the required safety load package.

The offsite power transfer operability check is performed to ensure that the plant emergency buses transfer to off-site power in the event of a loss of on-site power. The relays and bus transfer equipment are extremely reliable and past performance history confirms that the surveillance is extendible to 48 month intervals.

The Uninterruptable Power Supply (UPS) undervoltage relay checks are comparable to the undervoltage relay checks described in section 3.1.4.2. The Agastat time delay relay cannot be checked on-line, but its performance history confirms that the testing is extendible to once every 48 months.

3.1.9.3 Category C Surveillances

There are not Category C electrical surveillances.

3.1.9.4 Summary of Electrical Surveillances

Table 3.10 compares the current 18 month surveillance program for electrical system surveillances to the recommended surveillance program for a 48 month fuel cycle based on the justifications provided above.

Electrical Systems Surveillance Summary

Table 3 - 10

Cycle Length	Category A	Category B	Category C
18 Months	32	814	----
48 Months	824	22	0

3.1.10 Technical Requirements

3.1.10.1 Discussion

Technical Requirements are surveillances that were originally part of the technical specifications that a utility has removed from the technical specifications and handles separately with the permission of the NRC. Although the technical requirements are part of the licensing basis for the plant and require a formal Significant Hazards Evaluation (10CFR50.59) to change, changes can be approved on-site and do not require prior

approval from the NRC to implement. The technical requirements cover the following major areas:

- Loose Parts Detection
- Snubber Inspections
- Fire Pump Operability Checks
- Hydrant and Fire Hose Inspections
- Fire Wrap/Fire Seals/Fire Damper Inspections
- Carbon Monoxide/Smoke Detector Calibrations
- Fire Protection System Tests
- Fire Accumulator Inspections

3.1.10.1 Category A Surveillances

With few exceptions, all the technical requirement surveillances can be performed on-line. The vast majority of fire stations and fire wrap inspection points are accessible with the reactor on-line. For the limited number that are inaccessible, past inspection history and the availability of most of the inspection points with the reactor on-line provide a high degree of confidence that the inaccessible points can be deferred to refueling outages at 48 months or made part of a hot list for performance during unplanned shutdowns..

Snubber inspections and functional testing require the most attention. In the candidate PWR there are 286 individual snubbers. There are two main types of snubbers in use, mechanical and hydraulic. The mechanical snubbers which were the original design, exhibit higher failure rates than the hydraulic snubbers because they are more susceptible to system vibration. Testing is currently performed with the reactor shutdown. Discussions with the snubber system engineer revealed two options that would make the snubber testing program compatible with a 48 month fuel cycle. First, since the technical specifications, which are the original basis for snubber testing, allow a snubber to be inoperable for up to 72 hours, plants could have an inventory of snubber spares that could be bench tested satisfactorily and then swapped with in-place snubbers with the plant on-

line. The replaced snubber could subsequently be bench tested and after passing its bench test, swapped for another in-place snubber and so on. This technique would allow on-line testing and still keep the excess inventory of snubbers to a minimum. Second, mechanical snubbers which are inaccessible during reactor operation should be replaced with the more reliable hydraulic snubbers. The performance history of hydraulic snubbers suggests that testing could be extended to 48 months.

3.1.10.2 Category B Surveillances

As discussed above, there may be a few inaccessible systems which cannot have a surveillance performed with the reactor on-line. In these few cases, material history and the surveillance record of the accessible systems will allow interval extension to 48 months.

3.1.10.3 Category C Surveillances

There are no Category C technical requirement surveillances.

3.1.10.4 Summary of Technical Requirement Surveillances

Table 3.11 compares the current 18 month surveillance program for plant technical requirement surveillances to the recommended surveillance program for a 48 month fuel cycle based on the justifications provided above.

Technical Requirement Surveillance Summary

Table 3 - 11

Cycle Length	Category A	Category B	Category C
18 Months	53	8	----
48 Months	61	0	0

3.1.11 Summary of Regulatory Based Surveillances

Table 3.12 provides a complete summary of the PWR regulatory based surveillances. The table compares the current 18 month surveillance program to the recommended 48 month surveillance program described in this chapter.

Comparison of 18 Month Regulatory Surveillance Program versus Recommended 48 Month Program

Table 3 - 12

		Current 18 Month Program		Recommended 48 Month Program		
Tech Spec	**Total Reqts**	**On-Line**	**Off-Line**	**Cat A**	**Cat B**	**Cat C**
In-Service Testing	229	60	169	147	67	15
Reactivity Control	17	12	5	13	4	0
Power Distribution	17	16	1	17	0	0
Instrumentation	436	318	118	390	44	2
Reactor Coolant	18	8	10	13	4	1
ECCS	16	6	10	9	5	2
Containment	81	25	56	61	20	0
Plant Systems	51	41	10	51	0	0
Electrical	846	32	814	824	22	0
Tech Reqts	61	53	8	61	0	0
Totals	**1772**	**571**	**1201**	**1586**	**166**	**20**

The thesis 48 month regulatory surveillance program recommends moving 1013 of the 1201 surveillances currently performed off-line to on-line performance modes. This would result in 1586 of the 1772 total surveillances (89%) being performed on-line as compared to the current 571 of 1772 surveillances (32%). Even discounting the additional 792 electrical system surveillances recommended for on-line performance which skews the numbers somewhat, the recommended 48 month regulatory surveillance

program moves 223 surveillances currently performed off-line to on-line performance modes. This increases the percent of non-electrical surveillances performed on-line from 58% (539 of 926) to 82% (762 of 926). These results are valuable and should be considered regardless of whether a 48 month cycle is implemented. The recommended program reduces the number of regulatory surveillances required to be performed during 24 month refueling outages to 83 (166/2) from its current value of 1201, virtually guaranteeing that refueling operations will be the critical path to outage completion. The fewer number of refueling outage surveillances also means that outside contractor assistance to complete refueling outage regulatory surveillances may not be required. This would result in a substantial savings.

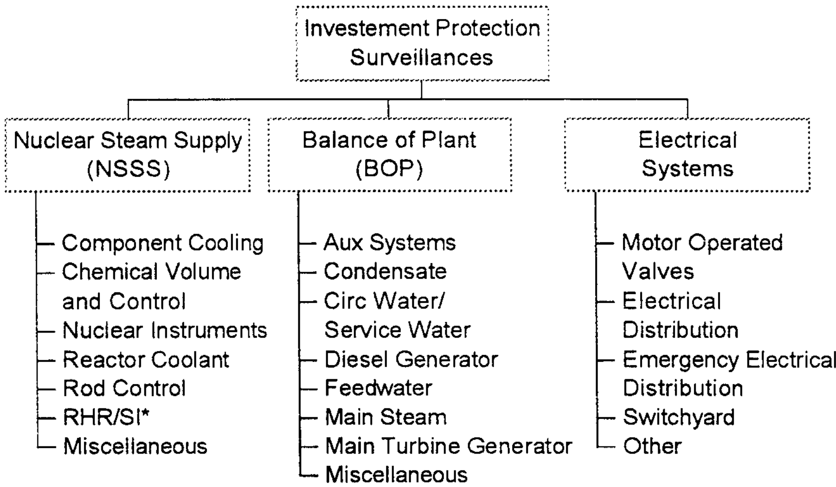
3.2 Investment Protection Surveillances

Investment protection surveillances include all the non-technical-specification-based surveillances performed at the candidate PWR. A small number of these surveillances are performed as a result of a commitments to agencies other than the NRC. In general, however, the investment protection surveillances discussed in this chapter are those whose performance mode and performance interval have been selected at the discretion of the utility to protect those systems and components with significant investment costs. The performance modes and performance intervals are selected to ensure that the reliability of the selected systems and components offsets the cost of performing the surveillance. Unlike the technical specification based surveillances discussed in section 3.1, utilities have much wider latitude in choosing which surveillances to perform and how often to perform them. Additionally, changes to investment protection surveillance performance modes or performance intervals can be made directly by the utility without a lengthy off site regulatory approval process. Ultimately, decisions as to whether to perform and how often to perform investment protection surveillances will be driven by how these particular surveillances change the Limiting Plant Event Frequency (LPEF) which is discussed in more detail in Chapter 2.

Investment protection surveillance programs are likely to vary widely from plant to plant. Because of this, they do not have a ready classification scheme such as the technical specification sections used for the regulatory based surveillance analysis. To provide a logical framework to analyze the investment protection surveillances, surveillances were grouped by system and placed into three main categories; Nuclear Steam Supply Systems (NSSS), Balance of Plant (BOP) systems, and Electrical systems. Several of the systems were further grouped into larger categories, such as main turbine systems which includes the main turbine generator and all its associated support systems. Figure 3-1 shows the overall structure adopted in for the investment protection program analysis.

Investment Protection Surveillance Categorization

Figure 3 - 1



*Residual Heat Removal/Safety Injection

Because of the large size of the investment protection surveillance program, only those investment protection surveillances currently performed while shutdown were evaluated for compatibility with a 48 month fuel cycle. There are over 1300 individual investment protection surveillances currently performed while shutdown at the candidate PWR. Of these, 457 surveillances have performance intervals which are already greater than 48 months and thus are already compatible with a 48 month fuel cycle. Many of these 457 surveillances are electrical surveillances similar to those discussed in section 3.1.9. Most of these surveillances can be performed on-line. They will be discussed further in section 3.2.3.

During the performance of the investment protection surveillance program analysis, many of the NSSS and BOP systems shown in figure 3-1 contained surveillances

which were electrically based. This included items such as motor-operated valve inspections and cable meggers, unitized starter checks, breaker inspections, and current injection testing of breakers. In these cases, these surveillances were not analyzed as part of that individual system, but were placed in the "Motor Operated Valve" and "Other" Electrical Systems categories. There were more than 450 surveillance items, with varying performance intervals, which fell into these two categories. This classification scheme resulted in a system analysis which contained only those surveillances unique to that system. This is consistent with the methodology used for the regulatory based surveillances discussed in section 3.1

3.2.1 NSSS Investment Protection Surveillances

3.2.1.1 Component Cooling (CC)

3.2.1.1.1 Category A Surveillances

There are eight CC surveillances currently performed shutdown which should be considered for on-line performance. These include calibrations of the four thermal barrier flow indicating switches and the two CC supply header temperature controls for the CC heat exchanger outlet and bypass valves. Additionally, the inspection and lubrication surveillance of the actuators for the two CC heat exchanger outlet and bypass valves can be performed on-line. The temperature control calibrations and the actuator inspection and lubrication of the CC heat exchanger outlet and bypass valves should be performed at the same time as they both require that the heat exchanger outlet temperatures be controlled in manual during surveillance performance.

3.2.1.1.2 Category B Surveillances

There are four CC surveillances currently performed shutdown which cannot be performed on-line whose performance intervals are already compatible with a 48 month

fuel cycle. The replacement of the transducers and the Bailey positioners for the CC heat exchangers temperature control valves are performed every 14 years.

3.2.1.1.3 Category C Surveillances

There are nine Class 2 relief valves in the CC system which cannot be tested or replaced on-line and whose performance history will not ensure reliable operation for 48 months between testing or replacement. Relief valves are discussed in more detail in Chapter 4.

3.2.1.1.4 Summary of Component Cooling Surveillances

Table 3.13 compares the current 18 month surveillance program for Component Cooing to the recommended surveillance program for a 48 month fuel cycle based on the justifications provided above.

Component Cooling Surveillance Summary

Table 3 - 13

Cycle Length	Category A	Category B	Category C
18 Months	----	21	----
48 Months	8	4	9

3.2.1.2 Rod Control (CP)

3.2.1.2.1 Category A Surveillances

There are six rod control surveillances currently performed while shutdown which should be considered for on-line performance. The four reactor trip breaker inspections can be performed on-line. Each breaker has an associated bypass breaker to allow on-line testing. The rod drive motor generator set overcurrent protective relay checks are allowed to be performed on-line with special permission from the operations manager. The special permission required from the operations manager recognizes the potential for

an unplanned reactor trip if the surveillance is not carefully planned and executed. Control Rod Drive Mechanism (CRDM) command traces can be obtained during the weekly step changes performed on each CRDM.

3.2.1.2.2 Category B Surveillances

There are 16 rod control surveillances currently performed shutdown which cannot be performed on-line but which can be performed at 48 month intervals while shutdown.

The control rod position indication operational test, rod control operability test, and the full speed and direction calibrations are similar to the rod position issues discussed in section 3.1.2.2. As long as the plant remains at power, tests of the rod control system which confirm its operability over the full range of rod motion are not required. If however, the plant shuts down after more than 18 months since the performance of the last rod control surveillance, then the surveillances should be performed prior to reactor startup.

There are five clean and inspects that can be deferred to 48 months. Three involve control panel clean and inspects and two involve rod drive motor generators inspections. To support the deferment, the inspection procedure should be augmented with some on-line inspections. On-line inspections must be limited to visual inspections of the cabinets and motor generators for loose connections and dirt. A thermographic inspection of the components will provide additional information for determining if they require an actual clean and inspect. The component louvers can also be covered with filtering material, such as Scott foam, to limit the amount of dust and dirt entering the components. The combination of visual inspections and thermographic inspections with the addition of filters should allow deferment of the actual clean and inspect to refueling periods. Clean and inspects cannot be performed on-line due to the dangers of working around energized gear and the possibility of spurious plant trips from dislodging various wires or circuit cards during the cleaning process.

The rod control system power supply has eight surveillances which can be performed at 48 month intervals. The CRDM stationary gripper fuses are currently

replaced every 36 months. Past performance indicates that the fuses are likely to remain reliable to at least 48 months. The rod control system DC power supply load test is performed every 36 months. Past performance indicates that the power supply is likely to remain in specification for at least 48 months. The five breaker inspections involving the motor generators and their power supplies are currently performed at 54 month intervals and are already compatible with a 48 month fuel cycle.

3.2.1.2.3 Category C Surveillances

There are no Category C rod control surveillances.

3.2.1.2.4 Summary of Rod Control Surveillances

Table 3.14 compares the current 18 month surveillance program for Rod Control to the recommended surveillance program for a 48 month fuel cycle based on the justifications provided above.

Rod Control Surveillance Summary

Table 3 - 14

Cycle Length	Category A	Category B	Category C
18 Months	----	22	----
48 Months	6	16	0

3.2.1.3 Chemical Volume and Control (CS)

3.2.1.3.1 Category A Surveillances

There are three CS surveillances currently performed shutdown which should be considered for on-line performance. The regenerative heat exchanger return inlet flow calibration can be performed on line. A bypass is available which allows the flow meter to be removed from service for calibration without interrupting flow to the heat exchanger. The flow meter is used to gauge long term flow performance of the system. Short term

removal for calibration is acceptable. The two centrifugal charging pump speed increaser lube oil pump couplings can be inspected on-line. Only one of two charging pumps is required at a time with the reactor at power. One charging pump can be tagged out and the surveillance easily conducted within an LCO.

3.2.1.3.2 Category B Surveillances

There are three CS surveillances currently performed shutdown which cannot be performed on-line but whose performance intervals are already compatible with a 48 month fuel cycle. Both centrifugal charging pumps mechanical seals are replaced and the bearings inspected once every four to six years. Depending on the time required to replace the mechanical seals and perform the bearing inspections these two surveillances could be considered for on-line performance. The Rotork valve actuator CS-V-189 inspection is performed every 54 months.

3.2.1.3.3 Category C Surveillances

There is one Class 2 relief valve in the CS system which cannot be tested or replaced on-line and whose performance history does not ensure reliable operation for 48 months between testing or replacement. Relief valves are discussed in more detail Chapter 4.

3.2.1.3.4 Summary of Chemical Volume and Control Surveillances

Table 3.15 compares the current 18 month surveillance program for Chemical Volume and Control to the recommended surveillance program for a 48 month fuel cycle based on the justifications provided above.

Chemical Volume and Control Surveillance Summary

Table 3 - 15

Cycle Length	Category A	Category B	Category C
18 Months	----	7	----
48 Months	3	3	1

3.2.1.4 Nuclear Instrumentation (NI)

3.2.1.3.1 Category A Surveillances

There are no Category A NI surveillances.

3.2.1.3.2 Category B Surveillances

There are four NI surveillances currently performed shutdown which cannot be performed on-line but whose current performance interval is compatible with a 48 fuel cycle. The gammametrics junction box o-rings are replaced every five years. The J10 relays for the excore neutron flux monitoring trains are replaced every 48 months. The incore detectors interconnecting tube removal and installation is performed as part of the refueling sequence and is independent of cycle length.

3.2.1.3.3 Category C Surveillances

There are no Category C NI surveillances

3.2.1.3.4 Summary of Nuclear Instrumentation Surveillances

Table 3.16 compares the current 18 month surveillance program for Nuclear Instrumentation to the recommended surveillance program for a 48 month fuel cycle based on the justifications provided above.

Nuclear Instrumentation Surveillance Summary

Table 3 - 16

Cycle Length	Category A	Category B	Category C
18 Months	----	4	----
48 Months	0	4	0

3.2.1.5 Reactor Coolant Systems(RC)

3.2.1.5.1 Category A Surveillances

There are 37 reactor coolant system surveillances currently performed shutdown which should be considered for on-line performance.

The 14 temperature calibrations on the auctioneered average temperature, loop delta temperatures, reactor vessel flange leak off system, pressurizer surge and spray lines, and the pressurizer relief discharge lines, can be performed on-line. The instruments are accessible at power. They provide indications and in some cases alarms of system temperatures, but provide no control functions. The calibrations can safely be performed on-line with other instruments providing enough information during the time the instruments are removed from service for calibration.

There are 12 temperature calibrations performed on the resistance temperature detectors (RTD) used to monitor the upper thrust bearing, upper radial bearing, and motor stator winding temperatures for each reactor coolant pump. The calibrations can be performed remotely from the RTD's at the reactor coolant pump temperature monitoring panel. Since the RTD's only provide temperature indications they can be safely removed from service for short periods of time on-line for calibration.

There are eight non technical specification relay inspections for each reactor coolant pump can be performed on-line. Each reactor coolant pump has an overcurrent relay inspection and a ground fault relay. Both relays are accessible and can be removed for testing without impacting on the operation of the reactor coolant pumps.

Several pressurizer surveillances are allowed to be performed on-line by procedure. These include pressurizer heater loops A and B calibrations, and the pressurizer level calibrations.

3.2.1.5.2 Category B Surveillances

There are 39 reactor coolant system surveillances currently performed shutdown which cannot be performed on-line but whose performance interval is either already compatible with a 48 month fuel cycle or can be extended to 48 months.

Each of the four reactor coolant pumps has several surveillances which are compatible with a 48 month fuel cycle. Gaskets on each reactor coolant pump are replaced once every 12 years. Each reactor coolant pump main flange area is currently inspected once every 18 months for boric acid buildup. A review of material history and discussions with the reactor coolant pump system engineer suggests that this surveillance could be safely extended to 48 months. A routine inspection of each reactor coolant pump motor is performed once every 18 months. This routine inspection requires that the pump and motor be uncoupled and thus requires the reactor to be shutdown. The inspection is a vendor recommended inspection. The reactor coolant pumps also undergo a more detailed inspection every four to five years when the motor is removed and sent to the vendor for a complete cleaning and overhaul. Material history records and discussions with the reactor coolant pump system engineer suggests that the detailed reactor coolant pump inspection is sufficient to maintain reliable operation of the reactor coolant pumps. Each of the three mechanical seals on the reactor coolant pumps is inspected and replaced if necessary every 48 months.

Several pressurizer related surveillances have current performance intervals of at least 48 months. The pressurizer heater control group controller inspection is performed every nine to twelve years. The pressurizer heater inspection is performed every 48 months. The pressurizer vent blank flange is removed and reinstalled to facilitate maintenance that is only performed during refueling outages and is thus independent of refueling interval.

The installation of the reactor coolant system vent and fill evacuation system, reactor coolant system draindown system, and steam generator nozzle dams are only performed as part of a refueling outage and are independent of cycle length. In preparation for reactor coolant system draindown. the reactor coolant system ultrasonic level instruments are calibrated.

The Valcor solenoid valves on the liquid sampling system are replaced every five years.

There is one residual heat removal suction relief valve type C leak test which will meet the 10CFR50 Appendix J leak test requirements and only needs to be performed every five years.

3.2.1.5.3 Category C Surveillances

There are eight Reactor Coolant System surveillances which cannot be performed on-line and whose performance intervals cannot be extended to be compatible with a 48 month fuel cycle. All eight surveillances involve the four Reactor Coolant Pumps and are discussed in more detail in Chapter 4.

3.2.1.5.4 Summary of Reactor Coolant System Surveillances

Table 3.17 compares the current 18 month surveillance program for Reactor Coolant Systems to the recommended surveillance program for a 48 month fuel cycle based on the justifications provided above.

Reactor Coolant System Surveillance Summary

Table 3 - 17

Cycle Length	Category A	Category B	Category C
18 Months	----	84	----
48 Months	39	37	8

3.2.1.6 Residual Heat Removal (RH)/Safety Injection (SI)

3.2.1.6.1 Category A Surveillances

There are no Category A RH/SI surveillances

3.2.1.6.2 Category B Surveillances

There are four RH/SI surveillances currently performed shutdown which cannot be performed on-line but whose performance intervals are already compatible with a 48 month fuel cycle. The Namco limit switches for valves RH-V-27,28, and 49 are replaced every 10 years (counts as three surveillances). The Valcor solenoid valves for the nitrogen vents to Safety Injection Accumulators A, B, C, and D are replaced every five years (all four valves are replaced as part of a single surveillance).

3.2.1.6.3 Category C Surveillances

There are no Category C RH/SI surveillances.

3.2.1.6.4 Summary of Residual Heat Removal (RH)/Safety Injection Surveillances (SI)

Table 3.18 compares the current 18 month surveillance program for RH/SI surveillances to the recommended surveillance program for a 48 month fuel cycle based on the justifications provided above.

RH/SI Surveillance Summary

Table 3 - 18

Cycle Length	Category A	Category B	Category C
18 Months	----	4	----
48 Months	0	4	0

3.2.1.7 Miscellaneous NSSS Systems Surveillances

Systems which did not interface directly with the reactor coolant system were classified as miscellaneous NSSS systems. These included:

• Containment Air Purge (CAP)	1 Surveillance
• Chemical Analysis (CAS)	16 Surveillances
• Containment Building Spray (CBS)	4 Surveillances
• Combustible Gas Control (CGC)	2 Surveillances
• Lead Detection (LD)	9 Surveillances
• Nitrogen Gas (NG)	2 Surveillances
• Head Removal (RE)	29 Surveillances
• Radiation Monitoring (RM)	10 Surveillances
• Spent Fuel Pool (SF)	6 Surveillances
• Waste Gas (WG)	3 Surveillances

3.2.1.7.1 Category A Surveillances

There are 44 miscellaneous NSSS system surveillances currently performed shutdown which should be considered for on-line performance. These include:

- 16 hydrogen monitor instrument calibrations
- 9 leak tests on various personnel and equipment hatches
- 2 nitrogen gas system auxiliary relay magnet block change outs
- 10 radiation monitor calibrations
- 4 maintenance items on the spent fuel pools
- 3 waste gas system calibrations

3.2.1.7.2 Category B Surveillances

There are 40 miscellaneous NSSS surveillances currently performed shutdown whose performance intervals already support a 48 month cycle or whose performance interval can safely be extended to 48 months. These include:

- One containment air purge surveillance involving removal of temporary spoolpieces
- Two containment building spray Type C leak rate tests
- Two containment building spray refueling outage protective cover removals
- Containment gas control temporary spoolpiece installation and removal
- 29 Surveillances involving preparations for and vessel head removal for refueling
- Three spent fuel surveillances with performance intervals of 54 months or more

3.2.1.7.3 Category C Surveillances

There are no Category C miscellaneous NSSS system surveillances.

3.2.1.7.4 Summary of Miscellaneous NSSS Systems Surveillances

Table 3.19 compares the current 18 month surveillance program for the miscellaneous NSSS surveillances to the recommended surveillance program for a 48 month fuel cycle based on the justifications provided above.

Miscellaneous NSSS Surveillance Summary

Table 3 - 19

Cycle Length	Category A	Category B	Category C
18 Months	----	84	----
48 Months	44	40	0

3.2.2 Balance of Plant (BOP) Investment Protection Surveillances

3.2.2.1 Auxiliary Systems

Auxiliary systems are second tier systems which support the functions of the major balance of plant equipment such as the main feedwater pumps and the main turbine generator. The BOP systems classified as auxiliary systems include:

- Extraction Steam (EX) - 13 surveillances
- Heater Drains (HD) - 31 surveillances
- Moisture Separator Drains (MD) - 9 surveillances
- Miscellaneous Vent and Drains (MVD) - 5 surveillances
- Steam Generator Blowdown (SB) - 6 surveillances
- Secondary Component Cooling (SCC) - 2 surveillances
- Steam Seal Supply (SSS) - 3 surveillances

3.2.2.1.1 Category A Surveillances

There are 35 auxiliary system surveillances currently performed shutdown which should be considered for on-line performance.

Extraction Steam - Three extraction steam leak checks can be performed on line.

Heater Drains - The two heater drain pumps have six surveillances which can be performed on-line. The recirculation control calibration checks can be performed on-line by placing the heater drain pump recirculation valves in manual control while the calibration checks are performed. The heater drain pump upper and lower motor bearings oil can be replenished and sampled with the pumps running. Additionally, the two overcurrent relay inspections for these two pumps are allowed on-line by procedure. Each of the 16 feedwater heaters level control calibrations can be performed on-line. The calibrations involve both the level control valves on the outlet of the heaters and calibrations on the spill valves for each of the heaters. The calibrations can be performed on-line by taking manual control of each of the level control valves during the performance of the calibrations. The heater drain tank pressure and level control

calibrations can also be performed on-line by controlling both pressure and level manually. Finally, the stroke calibration of the tempering valves to the heater drain pump suctions can be performed while controlling the tempering valves in manual.

Moisture Drains - The calibration of the four moisture separator reheater high level systems can be performed on-line. Each reheater has three level switches associated with it. Two of the three switches must sense high level to actuate an alarm and open a valve which will dump water from the reheater. One switch at a time can be removed for calibration with the plant on-line during steady state operations.

Secondary Component Cooling - The SCC supply header temperature calibration can be performed on-line by controlling flow manually while the calibration is in progress.

Steam Seal Supply - Calibration of the two turbine generator steam seal pressure systems can be performed on-line by manually controlling steam seal supply pressure while the calibration is in progress.

Performance of all the above mentioned calibrations should be performed during steady state operations to minimize the necessity for manual adjustments to the systems. If load changes are planned, the calibrations should be deferred to limit the risk of transients in the associated systems.

3.2.2.1.2 Category B Surveillances

There are 36 auxiliary systems currently performed shutdown whose performance interval is compatible with a 48 month fuel cycle.

Extraction Steam - There are 10 surveillances which perform maintenance on Gimpel (Miller Fluid) Actuators for valves in the extraction steam system. These surveillances have a current performance interval of 54 months and thus are already compatible with a 48 month cycle.

Heater Drains - The alignment of the level control systems for the 16 feedwater heaters is currently performed every 36 months. The candidate PWR is considering extending this to 48 months as part of their 24 month fuel cycle program. Because the calibrations can be performed on-line, it is likely that the alignments only need to be

performed every 48 months while shutdown. The heater drain pump rotating assemblies are scheduled for replacement every 36 months. Past performance history of the pumps indicates that this is probably excessive and would therefore support at least a 48 month replacement interval. A performance based system which determines whether the rotating assembly should be replaced based on vibration, lube oil analysis, or pump operating characteristics should be strongly considered. The heater drain pumps suction strainers are cleaned every 18 months. The strainers are cleaned following prolonged system shutdowns, such as during a refueling outage, when air is most likely to enter the system and cause increased levels of loose general corrosion products in the piping. Once the initial system cleanup has been completed, the strainers can be removed for full power operations. The system can be flushed using the on site auxiliary boiler as a steam and water source just prior to the end of a refueling period, and the strainers then removed for extended cycle operations. The heat exchangers for the heater drain systems are inspected every 18 months. The performance history for these stainless steel heat exchangers suggests that their inspection frequency could safely be extended to 48 months.

Moisture Drains - The reheater drain tank level control calibration is currently performed every 54 months and is therefore already compatible with a 48 month fuel cycle.

Steam Generator Blowdown - There are six valves in the SB system which require ASCO solenoid valve replacement every five years. These six surveillances are already compatible with a 48 month fuel cycle.

3.2.2.1.3 Category C Surveillances

There are seven auxiliary system relief valve surveillances which cannot be performed on-line and whose past performance makes it unlikely that the performance interval could be extended to 48 months. These are discussed in more detail in Chapter 4.

3.2.2.1.4 Summary of Auxiliary System Surveillances

Table 3.20 compares the current 18 month surveillance program for BOP Auxiliary Systems to the recommended surveillance program for a 48 month fuel cycle based on the justifications provided above.

Auxiliary Systems Surveillance Summary

Table 3 - 20

Cycle Length	Category A	Category B	Category C
18 Months	----	83	----
48 Months	35	41	7

3.2.2.2 Condensate System

3.2.2.2.1 Category A Surveillances

There are 14 condensate surveillances currently performed shutdown which should be considered for on-line performance.

The calibrations of the Condensate Storage Tank level control valve, Condensate pump recirculation valves, Feed pump seal water discharge pressure valves, Feed pump seal water differential pressures valves, and the Main Condenser recirculation valve can all be performed on-line by taking manual control of the valves during performance of the calibrations.

The Condensate pump discharge pressure calibrations can be performed on-line. Only two of the three condensate pumps are required for full power operations. The pumps can be rotated on-line to allow performance of the pressure calibrations.

The Feed pump suction header pressure switch calibration can be performed on-line. The suction header pressure provides an input which will trip the Feed pump. The trip occurs on a two of three logic for each Feed pump. Each pressure switch can be removed from service individually for calibration.

The Main Condenser boots on the three sections of the Main Condenser are accessible at power and these surveillance inspections can also be performed on-line.

3.2.2.2.2 Category B Surveillances

There are no Category B condensate surveillances.

3.2.2.2.3 Category C Surveillances

There are three condensate surveillances currently performed at 18 month intervals which cannot be performed with the turbine on-line and whose performance history will not allow the surveillance performance interval to be extended to 48 months. All three surveillances involve condenser waterbox maintenance. They are possible candidates for performance during a reduced power window as discussed in section 3.2.4. They are discussed in more detail in Chapter 4.

3.2.2.2.4 Summary of Condensate System Surveillances

Table 3.21 compares the current 18 month surveillance program for the Condensate System to the recommended surveillance program for a 48 month fuel cycle based on the justifications provided above.

Condensate System Surveillance Summary

Table 3 - 21

Cycle Length	Category A	Category B	Category C
18 Months	----	17	----
48 Months	14	0	3

3.2.2.3 Circulating Water/Service Water Systems

Although the Circulating Water (CW) and Service Water (SW) provide cooling water for different components and systems, they are similar in terms of function and the source of water they use as the cooling medium. Thus, they will be considered together for this analysis.

3.2.2.3.1 Category A Surveillances

There are 14 CW/SW surveillances currently performed shutdown which should be considered for on-line performance.

There are twelve surveillances which perform checks on the circulating water system. The circulating water system consists of three pumps. At full power, all three pumps are required. The requirement is based on a maximum allowed temperature rise of 20° across the condenser based on environmental regulations. Conversations with plant engineers indicated that the temperature limit can be observed with only two circulating water pumps up to 92% power. Additionally, the candidate PWR is investigating upgrading the existing pumps so that the temperature limits can be observed with only two pumps. The performance of circulating water surveillance checks which require a pump to be removed from service therefore require reduced power operations. Three of the surveillances check that the circulating pump lubricating water low flow alarms actuate on a loss of lubricating water to the circulating water pump. Water is provided to the stuffing box, pump bearing, and motor bearing for each of the three one third capacity circulating water pumps. To check each flow switch, the valve providing lubricating water to that portion of the pump is closed momentarily to confirm that the low flow alarm actuates. The traveling screens on the suction of each pump are removed for inspection every 18 months and should also be performed while each pump is secured for other testing. The final checks that should be performed while the pump is secured is an inspection of the lubricating water ports to the stuffing box and pump bearings and an inspection of the lubricating water ports to the motor bearing. These checks could be delayed if the flow checks on the lubricating water piping and pump and motor bearing temperatures show no degrading trend in performance. A review of past performance history shows that the traveling screen inspection takes on average about 21 hours to perform. Therefore a three day reduced power window is needed to complete all three traveling screen inspection surveillances.

The two service water inspections of the service water traveling screens are identical to those for the circulating water system and should be scheduled concurrently.

3.2.2.3.2 Category B Surveillances

There are five CW/SW surveillances currently performed shutdown which cannot be performed on line but whose performance interval is already compatible with a 48 month fuel cycle. The rotating assemblies for the three circulating water pumps and the two service water pumps are scheduled for replacement every 54 months. While this is already compatible with a 48 month cycle, performance monitoring should be used to determine if the rotating assemblies require replacement this frequently.

3.2.2.3.3 Category C Surveillances

There are no Category C CW/SW surveillances

3.2.2.3.4 Summary of Circulating Water/Service Water System Surveillances

Table 3.22 compares the current 18 month surveillance program for Circulating Water/Service Water Systems to the recommended surveillance program for a 48 month fuel cycle based on the justifications provided above.

CW/SW Surveillance Summary

Table 3 - 22

Cycle Length	Category A	Category B	Category C
18 Months	----	19	----
48 Months	14*	5	0

*All 14 at reduced power (<92%)

3.2.2.4 Diesel Generator Systems

3.2.2.4.1 Category A Surveillances

There are 26 diesel generator surveillances currently performed shutdown which should be considered for on-line performance. Many of these surveillances can be

performed in conjunction with technical specification based diesel generator surveillances described in section 3.1.9.2 during a LCO. Allowed outage times of up to 14 days have been technically justified and approved by the NRC. Additionally, although many of these surveillances have 18 month performance intervals, the performance intervals should be considered for extension to at least 36 months as part of an overall diesel generator inspection program switch to 36 months being considered within the nuclear industry. Diesel generator surveillances which can be performed in conjunction with a one to two week allowed technical specification outage on each diesel generator include:

-Air cooling water temperature control loop calibration
-Pre-lube oil pump suction strainer element inspection
-Biannual exhaust valve removal and restoration
-Air start system air receiver inspection
-Engine cylinder O-ring replacement
-Injector cooling water header inspection
-Air and fluid systems leak testing
-Air header coupling O-ring replacement
-Air start distributor maintenance
-Fuel injection pump stud inspection
-Diesel generator insulation check
-Crankshaft thrust bearing inspection
-Turbo-charger water jacket inspection

3.2.2.4.2 Category B Surveillances

There are two diesel generator surveillances currently performed shutdown which cannot be performed on-line whose performance interval is already compatible with a 48 month fuel cycle. The two emergency power sequencer relay inspections require the cabinets to be deenergized to perform the cleaning and inspection and should only be performed shutdown.

3.2.2.4.3 Category C Surveillances

There are no Category C diesel generator surveillances.

3.2.2.4.4 Summary of Diesel Generator System Surveillances

Table 3.23 compares the current 18 month surveillance program for Reactor Coolant Systems to the recommended surveillance program for a 48 month fuel cycle based on the justifications provided above.

Diesel Generator Surveillance Summary

Table 3 - 23

Cycle Length	Category A	Category B	Category C
18 Months	----	28	----
48 Months	26	2	0

3.2.2.5 Main Steam System

3.2.2.5.1 Category A Surveillances

There are 21 main steam surveillances currently performed shutdown which should be considered for on-line performance. The steam dump control calibration can be performed on-line. The steam dump valve has manual isolation valves upstream and downstream of the valve which will allow it to be isolated and tested on-line. The lubrication and inspection of the Terry turbine trip and throttle valve can be performed on line by isolating the steam supply to the turbine. The turbine provides a backup feedwater source and can be removed from service in an LCO. The thermographic inspection of pipe chase insulation is not dependent on plant status and should be performed on-line. The two ASDV noise silencer drain line inspections are typically performed off line because manual inspections of the piping are dangerous if one of the relief valves should lift during the inspection. However, the inspection and cleaning of the piping could easily be performed with remote controlled equipment that could perform both the inspection of the piping and removal of any debris without subjecting humans to the dangers of possible

exposure to high energy steam. Each of the Main Steam Isolation Valves (MSIV) has two trains of instrumentation which provide signals to shut the valves. Each train can be calibrated individually with the plant at power by taking manual control of the MSIV's. Each MSIV air motor lubrication can also be performed on-line during an LCO with the MSIV's controlled, one at a time, in manual.

The four MSIV's have both investment protection and regulatory based surveillances associated with them which are currently performed shutdown, but which can be performed on-line if plant power is reduced prior to surveillance performance. The four investment protection surveillances that must be performed at reduced power during a LCO involve periodic maintenance on the hydraulic fluid system which maintains the four MSIV's in the open position. The hydraulic fluid is drained, the fluid reservoir cleaned, and the in-line filter replaced at 18 month intervals. This can be done on one valve at a time and the plant maintained at <75% power. All the main steam surveillances as well as surveillances from other systems that require reduced power for on-line performance should be scheduled concurrently to minimize the length of any reduced power window. These surveillances are summarized in section 3.2.4.

3.2.2.5.2 Category B Surveillances

There are nine main steam surveillances currently performed shutdown which cannot be performed on-line but whose performance intervals would be compatible with a 48 month fuel cycle. The valve actuators for the four MSIV's and MS-V-393 have their solenoids replaced every four years. The elastometric components for the four MSIV's are currently replaced every three years. A review of their performance history suggests that that replacement of the elastometric components can safely be deferred to 48 months.

3.2.2.5.3 Category C Surveillances

There are six main steam relief valve surveillances which cannot be performed on-line and whose performance history will not allow the surveillance performance interval to

be safely extended to 48 months. Chapter 4 provides a more detailed discussion of relief valve surveillances.

3.2.2.5.4 Summary of Main Steam System Surveillances

Table 3.24 compares the current 18 month surveillance program for the Main Steam System to the recommended surveillance program for a 48 month fuel cycle based on the justifications provided above.

Main Steam Surveillance Summary

Table 3 - 24

Cycle Length	Category A	Category B	Category C
18 Months	----	39	----
48 Months	21*	12	6

*Four at reduced power (<75%)

3.2.2.6 Feedwater System

3.2.2.6.1 Category A Surveillances

There are 45 feedwater surveillances currently performed shutdown which should be considered for on-line performance. A large number of the surveillances involve the two 50% capacity steam driven main feed pumps. Calibrations of instruments which only provide alarms or valve control of valves which can also operated in manual, are readily adaptable to on-line performance. These instruments typically have isolation valves which allow them to removed on-line for calibration. The parameters measured by these instruments can be monitored locally during the performance of the calibrations to ensure they are remaining within specification. Instruments which provide signals to trip the feed pumps or control the level in the steam generators are more delicate to calibrate on-line because improper performance could result in significant plant transients. These instruments typically have two or more sensors, with multiple sensor inputs required to initiate the trip. If a plant analysis shows that there is a significant change in the plant trip frequency by performing these types of calibrations on-line, then consideration should be

given to performing the calibrations during a reduced power window where steam generator level is much easier to control in manual or the loss of one main feed pump would not result in a plant transient large enough to cause a plant trip. Individual surveillances are described below based on their function in the feedwater system.

Alarms and Control. The main feed pump recirculation flow indication and control is designed to ensure that the main feed pumps maintain a minimum flow of 7,000 gallons per minute. The recirculation valves can be controlled in manual locally during testing and calibration. The main feed pump pressure and speed indication alarms can be calibrated on-line. Pressure and speed indications can be monitored manually during performance of the pressure switch calibrations. The main feed pump discharge pressure alarms can be calibrated on-line and the discharge pressure monitored during performance of the test to ensure it remains within specification. The main feed pump oil pump discharge pressure calibrations are currently performed every four years while shutdown. However, these calibrations can safely be performed on-line by placing either the alternate or emergency oil pumps on the line in manual.

Trips and Feedwater Regulating Valve (FRV) Control. The main feed pump turbine bearing oil and low vacuum trip switch calibrations can be performed on-line. Each pump contains two switches which can be bypassed, one at a time, for testing. The main feed pump emergency oil pump pressure switch calibration can be performed on-line by placing the emergency lube oil pump in run and swapping the pressure switch, which turns the pump on upon sensing low lube oil pressure in the pump, with a bench tested spare. The main feed pump turbine trip header oil pressure calibration is similar to the pump oil pressure calibration and can also be performed on-line. The four surveillances which check the position indication and stroke times of the feedwater regulating valves requires power to be less than 15% to perform to prevent excessive changes in steam generator levels during the valve strokes. These four surveillances should be planned during a reduced power window. During performance of the surveillances steam generator levels can be controlled using the feedwater regulating valve bypass valves which are designed to control steam generator levels with power less than 15%. The bypass valves to the feedwater regulating valves can be calibrated and stroked with the

plant at power as long as the feedwater regulating valves and the steam generator water level control system are maintained in the automatic mode. The main feed pump suction header pressure is monitored by three individual pressure switches. Two of the three pressure switches are required to cause a main feed pump trip. Each switch can be calibrated individually on-line. The main feed pump speed control calibrations can only be performed with the main feed pump secured. This surveillance will require a reduced power window so that one pump at a time can be secured for speed control calibrations.

The steam generator steam and feedwater flow instruments provide inputs into the steam generator water level control system (SGWLC). Calibration of these instruments can be performed by idling one steam generator (securing all feeding and steaming) at a time and performing the calibration of the associated steam and feedwater flow instruments. In this way, the SGWLC system will not receive inputs from the idled steam generator instruments and will be able to properly control level in the three remaining steam generators with the plant at approximately 75% power. Past performance records indicates that the calibrations on each steam generator feed and steam flow instruments takes approximately 24 hours.

The four steam generator feedwater isolation valves have two surveillances each which can be performed on-line during a reduced power window. The feedwater isolation valves are designed to sense rapid drops in steam generator pressure caused by a steam line rupture and shut just upstream of the steam generator to stop the steam rupture. Each feedwater isolation valve has three Borg Warner pressure switches, two of which are required to actuate to trip the valve. The testing of the switches requires that the feedwater isolation valves be cycled several times. This can only be performed with the steam generator idled and the plant at reduced power below 75%. Prior to completing the pressure switch tests, the surveillances which clean and replace the lube oil to the feedwater isolation valve actuators should be performed. These surveillances can also be performed during a reduced power window with the steam generators idled one at a time.

The Startup Feed pump is used to control steam generator level with power less than three percent. With the plant at power, the pump can be removed from service and the surveillances which check the overcurrent relay, ground detection relay, perform trip

checks on the output breaker, and change the grease on the pump coupling performed on-line. Shaft voltage checks between the main feed pump and main feed pump turbine are external measurements and can be performed on-line. The inspection of the brushes on the DC motors for the two lube oil pumps associated with each main feed pump can be performed one at a time with the main feed pump running and the plant at power.

3.2.2.6.2 Category B Surveillances

There are 15 feedwater surveillances currently performed shutdown which cannot be performed on-line but whose performance interval are already compatible with a 48 month fuel cycle. The main feed pump oil tank levels and temperatures are currently checked every 72 months and are already compatible with a 48 month cycle. Depending on the time required to perform the surveillance, they should be considered for performance during a reduced power window when the main feed pump is removed from service for the performance of other surveillances. The main feed pump turbine governor speed control and valve position calibrations are currently performed every 48 months and are already compatible with a 48 month fuel cycle. The four differential pressure transmitters for the feedwater regulating valves are replaced every 13 years. The diaphragm on the four feedwater regulating valve bypasses are replaced every 54 months. The four motor operated valves for the emergency feedwater system are tested every 54 months.

3.2.2.6.3 Category C Surveillances

There are no Category C feedwater system surveillances. Many of the Category A surveillances require reduced power operations including idling of individual steam generators. Each individual utility will have to make a decision as to whether they feel it is cost effective to operate at reduced power during performance of these feedwater system surveillances.

3.2.2.6.4 Summary of Feedwater System Surveillances

Table 3.25 compares the current 18 month surveillance program for the Feedwater System to the recommended surveillance program for a 48 month fuel cycle based on the justifications provided above.

Feedwater System Surveillance Summary

Table 3 - 25

Cycle Length	Category A	Category B	Category C
18 Months	----	60	----
48 Months	45*	15	0

*17 at reduced power levels from <75% to <15%

3.2.2.7 Main Turbine Systems

The main turbine system surveillances consist of surveillances for the main turbine and generator as well as the key support systems which support turbine generator operation. The main turbine systems include:

- Electrohydraulic Control System (EHC) 24 surveillances
- Generator Stator Cooling (GSC) 11 surveillances
- Hydraulic Fluid (HF) 3 surveillances
- Lube Oil (LO) 9 surveillances
- Turbine Generator (TG) 6 surveillances
- Turbine Support (TSI) 5 surveillances
- Miscellaneous Procedures (MM) 16 surveillances

3.2.2.7.1 Category A Surveillances

There are 49 main turbine systems surveillances which are currently performed shutdown which should be considered for on-line performance.

EHC. Twenty two EHC surveillances currently performed shutdown should be considered for on-line performance during a reduced power window with the main turbine secured. The EHC system flow demand signal indication calibrations and the thrust bearing wear detector indication loop calibrations can be performed on-line. Neither signal provides an input which could cause a turbine and plant trip. The calibrations of the turbine generator first stage pressure, intermediate stage pressure, throttle pressure transducers, as well as the calibration of the turbine generator emergency trip system pressure switches and master trip pressure switches must be performed with the main turbine tripped. Thus, these calibrations must be performed during a reduced power window. Past maintenance records indicate that the calibrations require about 24 hours to perform. During performance of the transducer and pressure calibrations, several EHC electrical surveillances should also be scheduled for performance including cabinet clean and inspects, power supply adjustments, voltage comparator checks, and terminal box internal wiring checks. While the turbine is secured, the turbine generator speed probe gap measurements and speed cable integrity checks which also require the turbine to be secured can also be performed. Finally, the eight turbine generator servo valve strainer assembly replacements require the turbine to be secured and should be scheduled during the reduced power window. Based on historical records, strainer replacements take one to two hours to complete.

GSC. The GSC system which removes heat from the generator stator contains two pumps, each of which is capable of providing the necessary flow to remove the heat from the helium gas used to cool the generator stator. There are 11 GSC surveillances currently performed shutdown which should be considered for on-line performance. Four of these surveillances are recommended for performance with the main turbine secured as part of the trip avoidance program and thus should be scheduled during a reduced power window. These include switch calibrations for the GSC water pressure, inlet flow low, and turbine generator bushing coolant flow. The remaining seven surveillances are not part of the trip avoidance program and could be scheduled for performance during any on-line maintenance period. Plants may want to combine these surveillances with the four trip avoidance surveillances and complete all the GSC surveillances during the reduced power

window if the additional surveillances are not the critical path to returning to power. These surveillances include water inlet pressure control calibrations, GSC cooling pumps low pressure switches, stator coolant resin replacement, turbine generator bushing coolant flow calibration, GSC water temperature control calibrations, rectifier cooling water inlet drain pressure low calibration, and undercurrent relay inspections of the GSC control panel. These seven surveillances only provide indications as opposed to the trip signals provided by the first four surveillances.

HF. The hydraulic fluid system provides the high pressure hydraulic fluid to the EHC control valves. There are two hydraulic fluid pumps, only one of which is required at any time to maintain system pressure. There are three HF surveillances currently performed shutdown which should be considered for on-line performance. The three surveillances test the low pressure start features of each pump, the hydraulic fluid low trip pressure switch, and hydraulic pump filter differential pressure switch. Each test can be performed on a standby pump, with the pump in standby alternated with the on-line pump to complete all the surveillance testing.

LO. There are five lube oil surveillances currently performed shutdown which should be considered for on-line performance. The main turbine low shaft pump discharge pressure and low bearing oil pressure calibrations require the main turbine to be shutdown during their performance and thus should be scheduled during a reduced power window. The thrust bearing wear detector trip consists of four pressure switches, with two of the four switches required to cause a turbine trip. One switch at a time can be safely removed for calibration with the plant on-line. The turbine generator bearing temperature detectors can be removed for inspection and bearing temperatures monitored with the use of a surface pyrometer during the short inspection interval. The main turbine has three lube oil pumps. The primary pump is run directly off the turbine shaft. The two standby electric lube oil pumps are for emergency use. Their DC motors can be inspected, one at a time, with the turbine on-line.

TG. There are three TG surveillances currently performed shutdown which should be considered for on-line performance. The excitation and shaft grounding inspection, installation and removal of the turning gear remote jog switch are both allowed to be

performed on-line by procedure and do not increase the likelihood of a main turbine trip. The exciter power rectifier Teflon tube inspection can also be performed on-line. The tubes are translucent and thus the inspections can be performed without tube removal by backlighting each tube with a strong light beam.

TSI. There are five turbine support instrument surveillances currently performed on-line which should be considered for on-line performance. All the surveillances involve calibration of the turbine water spray systems.

3.2.2.7.2 Category B Surveillances

There are 21 main turbine systems surveillances which cannot be performed on-line but whose performance interval can made compatible with a 48 month fuel cycle.

EHC. Several miscellaneous turbine indicator checks are already performed at 48 month intervals. The electronic trip solenoid valve (ETSV) filter replacement is currently conducted every 54 months.

LO. There are two LO surveillances which cannot be performed on-line but which have performance intervals greater than 48 months and are thus already compatible with a 48 month cycle. The lube oil temperature indicator calibrations are currently performed every nine years. The lube oil control circuit relay and breaker checks are performed once every 54 months.

TG. There are three TG surveillances performed on the generator exciter currently performed off-line which cannot be performed on-line but whose performance interval is already compatible with a 48 month cycle. The exciter inspection and field polarity reversal are currently performed every eight years. The exciter field rotor removal and installation is currently performed every 54 months.

MM. There are 16 miscellaneous procedures performed on the main turbine which cannot be performed on-line but whose performance interval can be made or is already compatible with a 48 month cycle. The main generator megger/field resistance check is currently performed every 18 months. A review of past material records showed that the megger and resistance checks were satisfactory during each check over the past six years.

Additionally, a ground detection system continually monitors the generator and will give indications of possible degradation in generator resistance between inspections. This surveillance should be extended to 48 months. There are 13 surveillances which perform major inspections of the high pressure and low pressure turbines, generator rotor, and all the associated bearings for the turbine and generator. These surveillances are currently scheduled once every 72-96 months and are compatible with a 48 month fuel cycle. The generator field polarity reversal is also only performed once every 72-96 months. The turbine generator lay-up procedure is performed during prolonged shutdowns and is independent of cycle length.

3.2.2.7.3 Category C Surveillances

There are no Category C Main Turbine Systems surveillances. Many of the Category A surveillances require reduced power operations including securing of the main turbine with the reactor on-line. Each individual utility will have to make a decision as to whether they feel it is cost effective to keep the turbine idle for several days with the reactor on-line for surveillance testing. This issue is discussed in more detail in Section 3.2.4.

3.2.2.7.4 Summary of Main Turbine Systems Surveillances

Table 3.26 compares the current 18 month surveillance program for Main Turbine Systems to the recommended surveillance program for a 48 month fuel cycle based on the justifications provided above.

Main Turbine Surveillance Summary

Table 3 - 26

Cycle Length	Category A	Category B	Category C
18 Months	----	72	----
48 Months	49*	23	0

*28 at reduced power with main turbine secured (<20%)

3.2.2.8 Miscellaneous BOP Systems

There are several investment protection surveillances performed on systems which, with few exceptions, have no direct impact on the operation of the balance of plant equipment. These include surveillances involving fuel handling equipment, lighting, miscellaneous procedures, vibration analysis, and the public address system.

3.2.2.8.1 Category A Surveillances

There are 93 miscellaneous BOP system surveillances which should be performed on-line. These include all the surveillances dealing with fuel handling equipment (36), lighting (3), vibration analysis (22), public address systems (8), and 24 of the 33 miscellaneous procedures.

3.2.2.8.2 Category B Surveillances

There are nine miscellaneous procedures currently performed shutdown which cannot be performed on-line but whose performance intervals are already compatible with a 48 month fuel cycle. Four of the nine surveillances perform inspections of various plant control panels at 48 month intervals. The other five surveillances involve various containment hatch removals and installations which are only performed as part of a refueling outage and thus are independent of fuel cycle length.

3.2.2.8.3 Category C Surveillances

There are no miscellaneous BOP system Category C surveillances.

3.2.2.8.4 Summary of Miscellaneous BOP System Surveillances

Table 3.27 compares the current 18 month surveillance program for the miscellaneous BOP systems to the recommended surveillance program for a 48 month fuel cycle based on the justifications provided above.

Miscellaneous BOP Surveillance Summary

Table 3 - 27

Cycle Length	Category A	Category B	Category C
18 Months	----	102	----
48 Months	93	9	0

3.2.3 Electrical System Investment Protection Surveillances

Electrical related surveillances make up more than half (690 of 1336) of the total investment protection surveillances performed at the candidate PWR. As with the regulatory based electrical surveillances, the vast majority of these surveillances can be performed on-line. Additionally, most of these surveillances also have current performance intervals which are already compatible with a 48 month fuel cycle. Because it was too time consuming and not of significant generic value, each of the electrical surveillances was not checked to determine its optimum performance category. Each individual utility will have to determine the proper mix of on-line and off-line performance for their plant which can be both safely and economically performed. The electrical system surveillances were broken into five principal categories. These areas are:

- Motor Operated Valves 119 surveillances
- Electrical Distribution 109 surveillances
- Emergency Electrical Distribution 67 surveillances
- Switchyard 64 surveillances
- Other 331 surveillances

Switchboard clean and inspects are a major class of electrical surveillances which will likely have to be performed more often than once every 48 months. Because of the high voltages in many of the switchboards, it is essential to that they be kept clean to minimize the risk of arching damage and potential electrical fires. Cleanliness levels can be improved by installation of simple filter pads on the louver areas of the switchboards. Thermographic inspections may also be used to help determine any impending hot spots in the switchboards which may require further investigation.

3.2.4 Surveillances Requiring Reduced Power Windows

There are a large number of investment protection surveillances which can only be performed on-line if the plant is operated at reduced powers. Most of these surveillances also have performance intervals well short of 48 months and thus a decision must be made as to whether to shutdown or perform the surveillances at reduced power with the reactor on-line. Because utilities have much wider latitude in choosing the performance interval and performance mode of these surveillances, each individual utility will have to determine the safest and most economic way to perform each of these surveillances.

Performance of the surveillances in a reduced power window offers several major advantages when compared to shutting down to perform the surveillances. First, the time to recover the plant to full power following surveillance performance is significantly reduced. In the case of surveillances which do not require the main turbine to be secured, return to full power can be accomplished in a matter of hours. Secondly, by maintaining the reactor plant and the steam plant hot, fewer thermal cycles over the life of the plant will be required. On-line performance also does not require the major changes in both reactor and steam generator chemistry that is required following shutdown. Finally, historically, plant equipment problems often occur on equipment that has been returned to service following shutdown, even though that same equipment had been running reliably prior to the shutdown.

On-line performance of the many of these surveillances does have some disadvantages. Because the plant is still at power, the possibility of a plant trip or transient is possible even though the reduced power condition should eliminate most of these concerns. Most importantly, for those surveillances which require the main turbine to be secured, the reactor is producing power and burning fuel but is not producing revenue generating electricity. Thus the economic penalty from burning the fuel may be greater than the extra time required to bring the plant back to full power from a shutdown condition. If this is the case, the utility should opt to shut the plant down for surveillances requiring the main turbine to be shut down.

Table 3.28 provides a summary of the surveillances recommended for performance during a reduced power window. The table also lists the recommended power level for

surveillance performance, the average time to perform the surveillance based on historical records at the candidate PWR, and whether the main turbine must be secured during surveillance performance.

Summary of Surveillances Recommended for Performance during Reduced Power Windows

Table 3 - 28

Description	Est. Time (hrs)	Power Level	Turbine Secured
Condensate System			
Condenser Waterbox Maintenance	20-25 hrs	<20%	Yes
EHC System			
Pressure Transducer Calibrations	6 hrs	<20%	Yes
Emergency Trip System Calibration	24 hrs	<20%	Yes
EHC Power Supply Calibrations	16 hrs	<20%	Yes
EHC Cabinet Cleaning	24 hrs	<20%	Yes
Servo Strainer Replacements	1-2 hrs	<20%	Yes
Feedwater System			
Steam and Feedwater Flow Calibrations	24 hours	<75%	No
Feed Control Valve Indication and Stroke	16 hours	<15%	No
Feedwater Isolation Valve Strokes	20-30 hours	<75%	No
Feedwater Isolation Valve Fluid Change	20 hours	<75%	No
Main Feed Pump Governor Checks	5 hours	<50%	No
Generator Stator Cooling			
System Pressure Switch Calibrations	4-6 hrs	<20%	Yes
Lube Oil			
Main Turbine Low Shaft Oil Pressure Cal	5 hrs	<20%	Yes
Low Bearing Oil Pressure Calibration	5 hrs	<20%	Yes
Main Steam			
MSIV Stroke Checks (Tech Spec)	4-6 hrs	<75%	No
MSIV Maintenance	17 hrs	<75%	No
Circ Water/Service Water			
CW/SW Pump Maintenance	2-3 hrs	<92%	No
Traveling Screen Inspection	20-24 hrs	<92%	No

3.2.5 Reduced Power Surveillance Window Economic Analysis

Based on the surveillances listed in Table 3.28 a simplified economic analysis and possible bounding sequence for performance of surveillances in reduced power windows

was developed. The bounding sequence shown in Figure 3-2, is one of several scheduling options that could be used to complete the recommended reduced power windows surveillances. For instance, utilities may choose to perform the reduced power sequences over the course of several weekends when their power demands are the lower rather than performing all the reduced power surveillances during one consecutive 10-11 day period as shown in Figure 3-2. If a utility chooses to perform the surveillances in short blocks, rather than in one longer period, all the surveillances which can be done in parallel at that given power should still be scheduled for completion to minimize the time required to be in a reduced power window. Additionally, since all the surveillances recommended for reduced power windows have performance frequencies of 24 months or more, they should all be scheduled for completion during the middle of the fuel cycle so that the reduced power surveillance option must only be exercised once during the entire 48 months cycle.

The economic analysis was performed as follows:

Assume: (1) Replacement Power Costs of $600K per day

(2) Ramp up and down times one day longer for shutdown strategy

Based on Figure 3-2, the number of days at each power during the 10 day reduced power window is:

92% - 3 days

75% - 4 days

50% - 1 day

0% - 2 days

Note: There is a small fuel penalty if the reactor is kept on-line during turbine maintenance. This penalty is estimated to be less than 5% of the total lost revenue from surveillance performance during a reduced power window.

Lost Revenue (in Millions) During 10 Day Reduced Power Window:

$0.6/day * 3 days * 0.08 = $0.14

$0.6/day * 4 days * 0.25 = $0.6

$0.6/day * 1 day * 0.50 = $0.3

$0.6/day * 2 days * 1.0 = $1.2

Lost Revenue **$2.24 Million** (Over 10 day reduced power window)

Days Shutdown for the Equivalent Cost of Performing Maintenance in Reduced Power Windows

2.24 Million/0.6 Million/Day = 3.7 days

Less extra up and down time 1 day

Max Time Allowed **2.7 days shutdown**

There are several pros and cons to performing surveillances in a reduced power window as opposed to a shutting down to perform the surveillances.

Pros

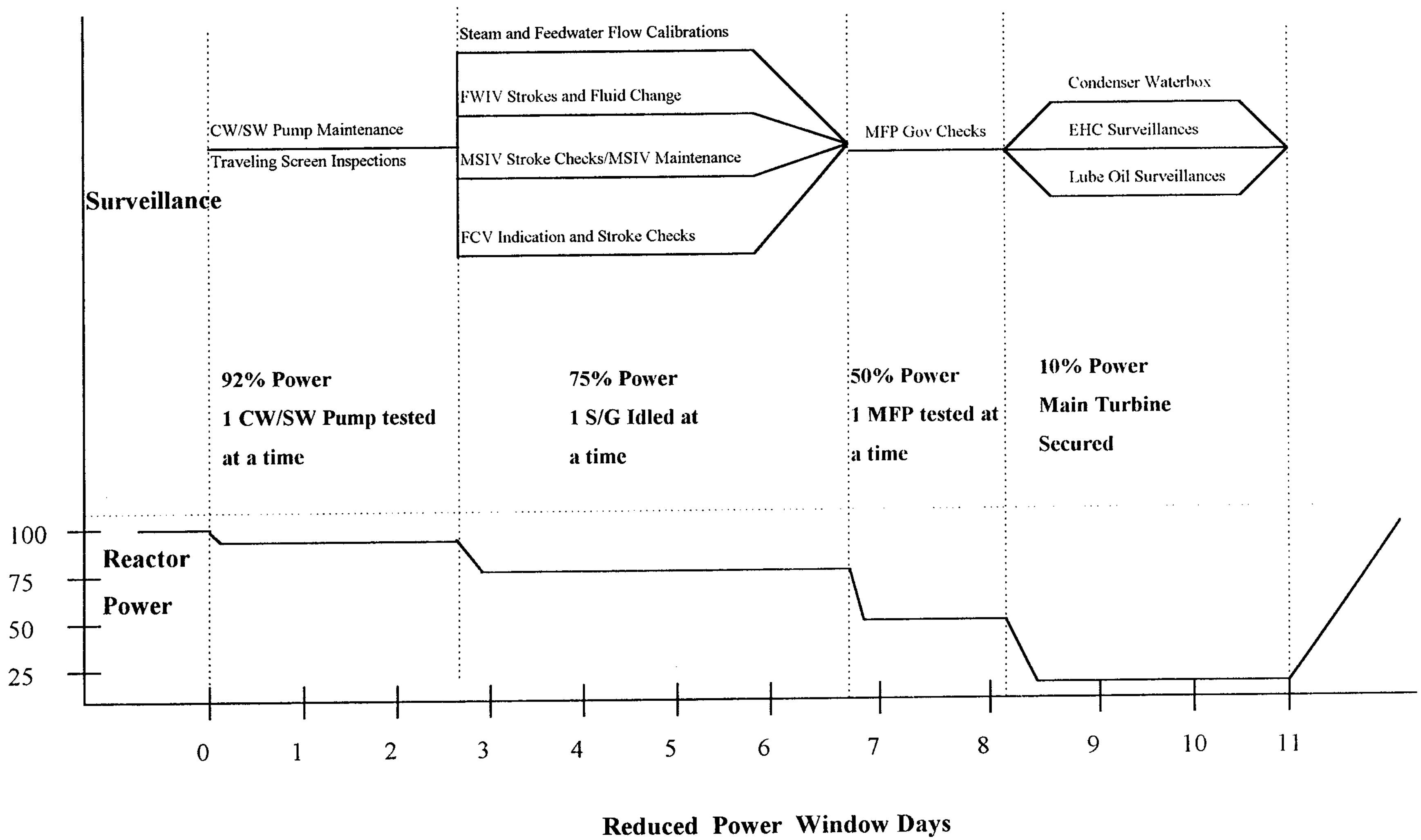
- Reduces thermal stresses and cycles on the plant
- Fewer primary and secondary chemistry changes
- Minimizes the amount of reliably running equipment that must be secured
- Reduced penalty, in general, for unexpectedly long surveillance completion times at power as compared to shutdown
- Allows immediate retests of equipment after surveillance performance

Cons

- Makes maintenance generally more difficult to perform because of heat/noise/radiation levels while at power
- Has unrecoverable costs from burning fuel burned while performing maintenance at self-sustaining conditions
- Results in abnormal plant lineups for several days which, although allowed, are not as familiar to the operators.

Example Reduced Power Window Surveillance Sequence

Figure 3 - 2



Conclusions

The shutdown strategy from a pure cost standpoint is effective only if the maintenance window can be completed in less than 2.7 days which may be difficult. Utilities must also take into account the pros and cons listed above when considering an overall strategy. Utilities must also recognize that there is likely to be an increased risk of a plant trip from on-line performance of these surveillances at reduced powers. A more detailed economic analysis which accounts for fuel costs in more detail, changes in plant trip frequency or limiting plant event frequency (LPEF), and the time savings from on-line performance of the surveillances performed must be conducted before a final decision on which, if any, of these surveillances should be performed in a reduced power window. Any of these surveillances which is not performed on-line must be placed in Category C and will require further study to remove the surveillance as a barrier to a 48 month fuel cycle.

3.2.6 Summary of Investment Protection Surveillances

Table 3.29 summarizes the recommended investment protection surveillance program at the candidate PWR, less the electrical surveillances.

Summary of Recommended Investment Protection Surveillance Program

Table 3 - 29

System	Number	Category A	Category B	Category C
NSSS	---	---	---	---
Component Cooling	21	8	4	9
Rod Control	22	6	16	0
Chem Vol and Control	7	3	3	1
Nuclear Instruments	4	0	4	0
Reactor Coolant	84	39	37	8
RHR/SI	4	0	4	0
Miscellaneous NSSS	84	44	40	0
BOP	---	---	---	---
Auxiliary Systems	83	35	41	7
Condensate	17	14	0	3
Circ Wtr/Service Wtr	19	14	5	0
Diesel Generator	28	26	2	0
Main Steam	39	21	12	6
Feedwater	60	45	15	0
Turbine Systems	72	49	23	0
Miscellaneous BOP	102	93	9	0
Totals	**646**	**397***	**215**	**34**

*67 at reduced power

The 690 electrical surveillances were not included in table 3-29, because as previously explained, the precise performance mode for each individual surveillance was not determined. Most of these 690 surveillances could be performed on-line and thus are likely to fall into Category A.

3.3 Summary of Recommended PWR Surveillance Program

This chapter includes the analysis of the entire surveillance program at an operating PWR. By doing this, the chapter has met two of the primary goals of this project. First, it has demonstrated that the regulatory and investment protection barriers to extended cycle lengths can be overcome. With the few exceptions discuss in detail in Chapter 4, the vast majority of the PWR surveillances are resolvable to a 48 month fuel cycle. Table 3-30 summarizes the entire PWR surveillance program, including the investment protection 690 electrical surveillances which were considered likely Category A surveillances. Of the 3108 surveillances considered at the candidate PWR, only 54 were considered potential barriers to an extended cycle. Sixty-seven of the 2673 Category A surveillances are candidates for on-line performance during a reduced power window. Second, this chapter in conjunction with the methodology presented in Chapter 2 has demonstrated a systematic surveillance resolution procedure that utilities can use to prepare for extended cycle lengths. As was previously stated, the recommendations provided in this chapter are valuable regardless of when an extended cycle is adopted. Implementation of the recommendations provided in this chapter will significantly reduce the number of surveillances required to be performed during 18-24 month refueling outages. This will result in cost savings from reduced outside contractor manpower requirements as well as the likelihood that the refueling sequence is now likely to be the critical path to power restoration.

Summary of Recommended
PWR Surveillance Program

Table 3 - 30

Type	Total	Cat A	Cat B	Cat C
Regulatory	1772	1586	166	20
Investment Protection	1336	1087	215	34
Totals	**3108**	**2673***	**381**	**54**

*67 at reduced power

Chapter 4 - Category C Surveillances

4.1 Introduction

All the Category C surveillances identified in Chapter 3 are collected and analyzed in more detail in this chapter. These are the set of surveillances which are currently identified as barriers to attaining a 48 month fuel cycle. Where available, possible engineering solutions to the Category C surveillances are proposed. Detailed engineering solutions to the complete set of Category C surveillances identified in this thesis will form the basis for significant future work for the MIT Extended Fuel Cycle Project team.

Hideki Masui in his thesis entitled "Quantitative Methodology for Surveillance Interval Extension at Nuclear Power Plants", May 1996, provided a methodology to quantitatively rationalize the proper surveillance interval. In it, he established the economic and safety requirements which are consistent with a longer operational cycle. The strategy and data requirements for the analysis are described in detail. This type of methodology provides a method for reexamining the Category C surveillances discussed in this chapter.

4.2 Regulatory Based Category C Surveillances

4.2.1 Relief Valves

At the candidate PWR plant there are 12 relief valve surveillances involving 38 individual relief valves which are currently performed shutdown at intervals less than 48 months. These relief valves cannot be tested on-line, and because of their performance history, testing is unlikely to be extendible to 48 months. These 38 valves include the three pressurizer relief valves which are Class 1 (primary pressure boundary) relief valves and 35 Class 2 (containment pressure boundary) relief valves.

The Operations and Maintenance of Nuclear Power Plants, ASME/ANSI (American National Standards Institute), OM-1987, Chapter 1, lists the requirements for in-service performance testing of nuclear power plant pressure relief devices. It requires that all Class 1

relief valves be tested every five years and that at least 25% of each type of Class 1 valve be tested every 24 months, 50% every 36 months, 75% every 48 months, and every relief be tested at least once every 60 months. Relief types are classified by their discharge diameter size in inches and how their design (i.e. spring actuated, pilot actuated). Plants have the option of testing their relief valves in place or replacing the relief valves with bench tested spares. With the exception of Main Steam Safety Valves, which because of their sheer size are usually tested in-place, most utilities opt to use the bench testing method to satisfy the code requirements. Class 1 relief valves which are replaced with bench tested spares are also required by the code to undergo bench testing after removal to determine if the valves exceeded the stamped set pressure criteria of 3% or greater at the time of replacement. For those Class 1 relief valves failing to meet the set pressure acceptance criteria, the causal effect must be evaluated to determine the need for additional tests[10]. Although the code, as currently written, precludes extending the test interval on Class 1 relief valves to 48 months, data at the candidate PWR received from the company which bench tests their replaced Class 1 relief valves shows that the pressurizer relief valves are always within specification when removed at 18 month intervals. This indicates that the requirement to test at least 25% of these relief valves every 24 months may be overly conservative and should be investigated. However, because of their safety importance, a more detailed technical analysis is needed to justify extending the performance interval on Class 1 relief valves to 48 months. The NRC Generic Safety Issues Branch (GSIB) in the Office of Nuclear Regulatory Research is currently reviewing failure modes and failure rates of relief valves and evaluating the advantages and disadvantages of possible changes to the ASME code testing requirements.[11]

As with Class 1 relief valves, utilities have the option of testing Class 2 relief valves in place or replacing the relief valves with bench tested spares. However, Class 2 relief valves are only required to be tested every 10 years with at least 25% of each type tested every 48 months. This would appear to make Class 2 relief valves already compatible with the 48 month extended fuel cycle. However, most plants are currently testing these relief valves on a more frequent basis

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[10] Operations and Maintenance of Nuclear Power Plant, ASME/ANSI, 1987, Chapter 1, p. 5.

[11] Cherny, Frank, USNRC Office of Research, Generic Safety Issues Branch, letter of 2 February 1996.

(18 to 24 months), and unlike the pressurizer relief valves discussed in the preceding paragraph, the performance of Class 2 relief valves has not proven historically to be good enough to allow testing at intervals of 48 months. During the most recent outage at the candidate PWR seven of the 31 Class 2 relief valves tested failed their lift test check after only 18 months of operation. This type of failure data precludes 48 month testing intervals of the 35 Class 2 relief valves which are in active systems and cannot be tested with the reactor on-line. Further analysis of industry wide relief valve failures, including the valve type, valve size, system fluid conditions, and environmental conditions at the relief location must be performed to determine the principal failure mechanisms and allow recommendations for improvement. Relief valves have universal applications and are used in many industries besides the nuclear industry so a large amount of data should be available for a detailed analysis. Additionally, if possible, trending of valve degradation with time should be considered. Valves with linearly increasing set pressure variations must eventually be corrected and will have problems with extended fuel cycles. Conversely, relief valves which exhibit a short term, large jump in pressure variation followed by stable operation may be satisfactory for long term operation. If the trend of valve degradation is not well understood, the wrong conclusions may be drawn regarding a valve's long term behavior and compatibility with an extended fuel cycle.

4.2.2 Motor Operated Valves

The candidate PWR has surveillances involving MOV's which cannot be performed on-line and are unlikely to be extendible to 48 months. MOV's have received widespread attention in the nuclear industry since the issuance of Generic Letter 89-10 (Safety Related Motor Operated Valve Testing and Surveillance). GL 89-10 requested that all MOV's in safety related systems have their design basis reverified, that the valves be set-up and diagnostically tested, and where practical tested to their design basis condition. A detailed review of all the MOV's at the candidate PWR as part of GL 89-10 requirements identified three basic categories of MOV's[12]:

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[12] O'Regan, p. 3.

1) MOV's that are position-changeable-only valves. Position changeable valves are valves which are normally in their safety related position and thus only require the motor to realign the valve to it's normal position following testing

2) MOV's with high safety significance and high differential pressures across the valve when required to actuate, and

3) MOV's with high safety significance and low differential pressures across the valve when required to actuate.

Using the above classifications, the valve failure rate (directly related to differential pressure) is combined with its risk significance to determine the acceptable testing interval for each valve. Because the failure rate for high differential pressure valves is significantly higher than the failure rate for low differential pressure valves, the failure rate, independent of the risk significance, is the dominant factor in determining the acceptable testing intervals.

Of the 122 MOV's at the candidate PWR, only six of the valves have high differential pressure operating conditions and high risk significance. These six valves have recommended performance intervals of 36 months. Of these six MOV's, only three cannot be tested with the reactor plant on-line. These three MOV's are covered by a single surveillance and are all valves in the Safety Injection System.. The remaining 116 MOV's either have testing intervals compatible with a 48 month cycle or have been recommended for removal from the surveillance program because they are changeable position valves which are already in their required safety position.

4.2.3 In-Service Testing

The ASME Boiler and Pressure Vessel Code, Section XI, "Rules for In-Service Inspection of Nuclear Power Plant Components", requires that all safety related pumps and valves be tested for operability on a quarterly basis. In some cases it is hazardous or simply impossible to perform the tests while the plant is at power. In general, surveillances which are hazardous to perform on-

line involve stand-by systems such as the Residual Heat Removal System or Safety Injection. Rather than shut down every three months to perform these operability tests, utilities may petition the NRC to designate a surveillance that cannot practically be performed with the reactor core installed as a refueling test and defer the surveillance to refueling periods. These requests can be augmented in the future by risk-based arguments Utilities may also opt to designate tests that are not as limiting as refueling tests but which still cannot be performed with the plant on-line as cold shutdown tests. Cold shutdown test justifications must be documented and can be audited by the NRC, but do not require prior approval of the NRC to designate them as a cold shutdown test. Once a surveillance is designated as either a Refueling or Cold Shutdown Test, it does not have to be performed every three months if the plant is operating continuously over that period of time. If however, a plant incurs an unplanned outage after more than three months from the last in-service testing period, the ASME code requires the following rules be followed for all surveillances designated as Cold Shutdown Tests:

- Testing is to commence as soon as practical when the Cold Shutdown condition is achieved, but no later than 48 hours after shutdown, and continue until all testing is complete or the plant is ready to return to power.

- Completion of all testing is not a prerequisite to return to power. Any testing not completed during one cold shutdown should be performed during any subsequent cold shutdown starting with those tests not previously completed done first.

- Testing need not be performed more often than once every 3 months.

- In the case of an extended cold shutdown, the testing need not be started within the 48-hour limitation. However, in extended cold shutdowns, all Cold Shutdown Testing must be completed prior to returning to power.

If a plant operates uninterrupted for an entire cycle, cold shutdown testing is only performed during refueling outages. Since the longest operating cycles in the United States are

approximately 24 months, the maximum current interval on a Cold Shutdown Test is 24 months. The question that then arises is is there an upper limit on the allowable length between cold shutdown testing? The ASME code does not address the question of how long is long enough, and opinions vary as to the likelihood of 48 month surveillance intervals being acceptable. Conversations with regulatory personnel and system engineers at the candidate PWR indicated that there is sufficient performance data available to make the case for interval extension on most of the components covered by the code.

If the interval extension cannot be technically justified, most of the designated cold shutdown surveillances are relatively simple to perform and are excellent candidates for a surveillance performance hotlist. This hotlist would track those surveillances which should be prepped and ready to be performed immediately whenever the plant is shutdown for any reason.

To further solve the in-service testing interval question new technologies should be investigated to provide a means of justifying surveillance performance intervals out to 48 months. Application of innovative monitoring technologies could provide enough on-line diagnostic information on the various pumps and valves to ensure operability upon demand. This would ultimately remedy the burden of maintaining some or all of the Cold Shutdown Operability Tests on the surveillance performance hotlist.

4.2.4 Engineered Safety Features

There are six separate surveillances involving three similar Engineered Safety Feature Actuation System (ESFAS) tests (two trains each) performed at the candidate PWR which cannot be performed on-line, and which are not likely to be extendible to 48 months. These are integrated tests which involve sensors, signal processing, and valve and pump actuation. They cannot be performed on-line because of the risk of injecting cold water into an operating reactor which will result in a large and potentially dangerous power excursion. Each test is described in more detail below.

4.2.4.1 Diesel Generator Operability and Engineered Safeguards Pump and Valve Response Time Testing

There are two integrated diesel generator operability and engineered safeguards pump and valve response time tests (one for each train) currently performed with the plant shutdown at 18 month intervals which cannot be performed on line, and which are unlikely to be extendible to 48 months. It may be possible to devise a safe test which would test the integrated features of all the safety systems involved with the exception of actually putting water into the core with the reactor critical. However, because this test is central to proving that cooling water can be delivered in sufficient quantities to prevent damage to the core and the containment in the event of a major Loss of Coolant Accident (LOCA), non-technical factors must also be considered when contemplating extending to 48 months those portions of this test that provide system proof of flow to the reactor vessel and containment. This surveillance should be studied further.

4.2.4.2 Actuation of Auto Safety Injection, Containment Building Spray, and Control Building Air systems

There are two surveillances in this category currently performed while shutdown at 18 month intervals which cannot be performed on line, and which are unlikely because of safety concerns to be extendible to 48 months. The two surveillances are identical (one for each train) and verify that the automatic safety injection, containment building spray, and control building air systems actuate within allowable time limits upon receipt of a test signal. The tests also verify that the manual alarms for these systems function correctly. These tests are typically performed in conjunction with the Diesel Generator Operability and Engineered Safeguards Pump and Valve Response Time Testing detailed in section 4.2.4.1. While it may be possible to design an integrated test which measures the response time of the instrumentation without any valve actuation, the test setup is likely to be very complex and place the plant in a very unstable condition during the testing because of the removal of one complete ESF train for an extended period of time. Further study of these integrated ESF tests is needed.

4.2.4.3 Emergency Core Cooling Systems Automatic Actuation Test

There are two identical surveillances, one for each ECCS train, currently performed off-line which cannot be performed on line, and which are unlikely to be extendible to 48 months. These tests are typically performed in conjunction with the other ESFAS integrated test included in sections 4.2.4.1 and 4.2.4.2. This surveillance tests that various ECCS systems will realign within specified time limits upon receipt of a SI signal including the initiation of feedwater isolation, diesel generator start, containment isolation, containment ventilation system isolation, and primary component cooling water system (PCC) realignment. While all but two of the motor operated valves in the test are recommended for testing at intervals greater than 48 months, and other individual parts of the test can probably be conducted on-line, a method to test the integrated nature of the system on-line requires further investigation.

4.2.5 Steam Generator Eddy Current Testing

Steam generator eddy current testing is currently performed shutdown at 18-24 month intervals. It cannot be performed on line, and is unlikely to be extendible to 48 months because of previous experience within the nuclear industry with tube failures due to stress corrosion cracking and aging. The current NRC inspection guidelines for steam generators allow for periods between steam generator eddy current testing of up to 40 months. This interval is allowed only after two previous successful inspections at shorter intervals. However, because of the difficulty planning for a constantly changing inspection interval, most PWR's opt to inspect all their steam generators every refueling outage regardless of the maximum allowable inspection interval. Thus, inspection intervals much greater than 24 months which might provide some data as to the long term performance of steam generator tubes are rare. Although many of the steam generator tube corrosion mechanisms have been virtually eliminated by proper temperature and chemistry control, the industry trend is towards more frequent inspections as the steam generators age.

Many utilities are now replacing their Inconel 600 steam generators with Inconel 690 steam generators which are supposedly less susceptible to stress corrosion cracking, one of the principal steam generator failure mechanism. However, these claims are based upon laboratory testing and have not been substantiated by inspection results from actual steam generators. An

extensive database of inspection results for Inconel 690 steam generators must be collected industry wide before the technical case can be made for increasing the interval between eddy current inspections to as much as 48 months. Further research is required in this area, including the possible use of state-of-the-art on-line monitoring tools. A program is underway at MIT headed by Professor Ronald Ballinger to develop a tool which would provide on-line tube integrity information.

The candidate PWR in preparation for transitioning to a 48 month fuel cycle recently completed a draft of a technical request to the NRC to extend the interval between Steam Generator tube inspections to 50 months. The technical evaluation concluded that tube degradation over the course of 50 months experienced in the type of steam generators used at the candidate PWR would not reduce the margins of safety required by NRC Regulatory Guide 1.121 "Bases for Plugging Degraded PWR Steam Generator Tubes", August, 1976. The candidate PWR uses four Westinghouse Model F with 5626 Thermally Treated, Inconel 600 U-tubes (SB-163), hydraulically expanded into the tubesheet at each end. The tube bundle is supported by "V"-shaped Anti-Vibration Bars in the U-tube bend region and eight stainless steel Tube Support Plates.[13] If approved by the NRC, it would eliminate eddy current testing as a barrier to an extended fuel cycle for those plants with excellent operating history and newer design steam generators. To date however, the NRC has not approved any extensions to 50 months. Therefore, eddy current testing is likely to remain a barrier for the majority of PWR plants.

4.3 Investment Protection Category C Surveillances

4.3.1 Relief Valves

At the candidate PWR plant there are 23 relief valve surveillances currently performed shutdown at intervals less than 48 months. These reliefs cannot be tested on-line, and because of their performance history, testing is unlikely to be extendible to 48 months. All the investment protection relief valves are Class 2 relief valves (containment boundary valves). The investment

[13] Candidate PWR, Technical Evaluation of Extended Inspection Intervals for SBK1 Steam Generator Tubes.

protection relief valves are the same design as the regulatory based relief valves. For a more detailed discussion of the basis for classifying relief valves in general as Category C surveillances refer to section 4.2.1

4.3.2 Condenser Waterbox Maintenance

The Main Condenser is the primary heat sink for the power plant. The ability to effectively transfer heat to the condenser is vital to the efficient performance of the entire plant. If the main condenser heat transfer capability is degraded, either the plant must be operated at reduced load or risk overheating and potentially severe damage to the condenser, including overpressurization and rupture.

The primary degradation mechanism of the heat transfer capability of the condenser is the clogging of the condenser inlet tube sheets and tubes from either debris or marine growth. Since most condensers use brackish water as the cooling medium (seawater, river/lake water), it is virtually impossible to totally prevent the buildup of debris or marine growth in the condenser. While the onset of reduced heat transfer capability can be delayed by the use of suction screens on the piping to the service water pumps, the only proven way to restore or maintain the condenser's heat transfer capability is by opening the condenser and manually cleaning the tube sheet faces and lancing the tubes themselves or on-line through the use of chemicals or abrasion balls. Even though the main condenser at the candidate PWR has three individual tube bundles which make up the main condenser they are not isolable for inspection with the main turbine on the line. Therefore, any opening of the condenser waterbox for inspection and cleaning will require the turbine and all steam loads to the condenser to be secured.

At the candidate PWR, the condenser waterboxes are currently cleaned once every 18 months. Maintenance records and discussions with system engineers indicate that the condensers require a thorough cleaning at the 18 month intervals.

The heat transfer performance of the main condenser can be continuously calculated by monitoring the service water temperature changes across the condenser and the main turbine vacuum. In this way, plant engineers can determine when the tube sheets are beginning to clog to such an extent that they must be cleaned to continue full power operations. At what point this

occurs has not yet been determined, and this point may vary depending on the season or makeup of the service water source. Even though the candidate PWR condensers currently receive a thorough cleaning at 18 month intervals, the condensers have not yet reached the point where a degradation in heat transfer capability has occurred, indicating that the performance interval could be safely extended past 18 months albeit not necessarily to 48 months.

One potential solution which may extend the interval between required condenser cleanings would be installation of piping which would allow the individual sections of the condensers to be back flushed one at a time. This type of flush could be performed with the turbine on-line, and although it would not eliminate all the debris or marine growth buildup in the condenser, it might eliminate enough so that the interval between waterbox inspections could be extended to 48 months.

The condenser waterbox maintenance may also be a candidate for performance during a reduced power window with the turbine removed from service. If the inspection and cleaning can nominally be performed in two to three days it should be considered for on-line performance. The economic analysis of Chapter 3, section 3.6.5, considered the impact of on-line performance of condenser waterbox maintenance assuming a two to three day performance window as shown in figure 3-2.

4.3.3 Reactor Coolant Pumps

There are eight reactor coolant pump surveillances which cannot be performed on-line because the pumps are not accessible at power, and whose past performance history suggests that they cannot be safely extended to 48 months. All eight surveillances deal with the reactor coolant pump lube oil system.

The check of the four reactor coolant pump oil level hi/lo alarm must be performed shutdown because the oil system for the reactor coolant pumps are not accessible at power and the pumps are required to be shutdown to check the alarms. The check is performed by varying the lube oil level in the pump oil reservoir with the reactor coolant pump secured to check the operation of the high and low level switches.

One possible solution for this surveillance would be to design the pump oil reservoir so that it would be accessible with the plant at power. The oil level switches could then be replaced with bench tested spares versus varying the actual oil level in the reservoir which would not be prudent with the reactor coolant pump running. In this way, the switches could be checked on a more frequent basis if necessary, and only then tested in place by varying the lube oil reservoir level at 48 month intervals with the pump secured. Additionally, if the lube oil reservoir for the pump could be made accessible with the plant at power, a sight glass could be installed to allow manual checks of the lube oil level when level switches were removed for replacement.

The lube oil in the reactor coolant pumps is sampled every 18 months and replaced if necessary. Conversations with the reactor coolant pump system engineer indicated that the lube oil often requires replacement at 18 month intervals. If an accessible oil reservoir described in the paragraph above is installed, lube oil sampling could be accomplished on-line to provide a means for determining, on a performance basis, when the lube oil in the reactor coolant pumps required replacement. Additionally, consideration should be give to installing an on-line purification system similar to those used for most main turbines. The purification system would allow the pumps to run for extended periods of time without having to change the oil. Additional oil could be added to the pump oil reservoir with the pump running if required.

Damage to a reactor coolant pump would certainly qualify as one of the major limiting plant events. Therefore, until changes are made which would allow on-line purification and sampling, shutting down to change the reactor coolant pump lube oil when required, even if it is inside of 48 months is the most prudent choice.

4.4 Summary of Category C Surveillances

Table 4-1 summarizes the PWR Category C surveillances. Additionally, based on plant historical records, estimates of the time required to perform each surveillance is included. Because the total time for the plant to be off line would include about a day to establish the plant conditions necessary to commence the surveillances and a day to bring the plant back on-line following the completion of all the surveillances, the total outage time is likely to be

approximately two weeks based on the time to complete the longest surveillance (Eddy Current Testing).

Summary of Category C Surveillances

Table 4 - 1

Surveillance Category	Investment Protection or Regulatory Based	Estimated Time
Relief Valve Testing	Investment/Regulatory	4 days
MOV Testing	Regulatory	1 day
Condenser Waterbox	Investment	2 days
ESFAS	Regulatory	10 days
S/G Eddy Current Testing	Regulatory	12 days

Chapter 5 - Surveillance Interval Extension Justifications

5.1. Introduction

This chapter presents an example of a performance interval extension justification conducted as part of an actual 24 month fuel cycle extension program at the candidate PWR. A detailed procedure for use in drafting similar interval extension requests to the NRC is provided in Appendix A. This procedure, which I drafted, is used as the basis for drafting all 24 month fuel cycle interval extension requests at the candidate PWR. The surveillance interval extension example provided here is intended to provide a general guide to utilities for use in developing justifications for performance interval extension. The example also demonstrates the type of effort required to perform a complete 48 month fuel cycle surveillance resolution project. For this thesis, complete justification of all candidate surveillances was a prohibitively large task. Because actual surveillance resolutions will vary somewhat from plant to plant, a complete surveillance justification program is left to the individual utility.

5.2. Performance Interval Extension Technical Evaluation

The following technical evaluation for surveillance interval extension was written for submission to the licensing department at the candidate PWR as part of an actual 24 month fuel cycle extension program. The significant hazards evaluation presented in Section IV of the evaluation will form the basis for the formal request for interval extension to the NRC. Although written for an extension from 18 to 24 months, the format and methodology used in this technical evaluation are applicable to any cycle length. A detailed procedure for completing licensing based technical evaluations is enclosed as Appendix A.

PWR STATION
24 MONTH FUEL CYCLE
TECHNICAL EVALUATION NUMBER 5F
FOR CHANGE TO
TECHNICAL SPECIFICATION NO. 4.7.3.b
PRIMARY COMPONENT COOLING WATER SYSTEM
AUTOMATIC VALVE SURVEILLANCE INTERVAL

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List of Attachments

TECHNICAL EVALUATION NUMBER 5F
FOR CHANGE TO
TECHNICAL SPECIFICATION NO. 4.7.3.b
PRIMARY COMPONENT COOLING WATER SYSTEM
AUTOMATIC VALVE SURVEILLANCE INTERVAL

SECTION I - TECHNICAL EVALUATION CONCLUSION

Technical Specification (T/S) Surveillance Number 4.7.3.b which is currently performed once per 18 months, can be performed at surveillance intervals of up to 30 months (24 months + 25%). The effect on plant safety is insignificant. Historical preventative and corrective maintenance records, surveillance data, other surveillances performed on system components, and a failure mode analysis validate this conclusion.. Additionally, the performance of the surveillance at the bounding surveillance interval limit (30 months) will not invalidate any assumption in the plant licensing basis.

SECTION II - DESCRIPTION OF CHANGE

The PCC automatic valves servicing safety related equipment are demonstrated operable every 18 months by verifying that each automatic valve servicing safety-related equipment actuates to its correct position on its associated Engineered Safety Feature (ESF) actuation signal in accordance with T/S No. 4.7.3.b. This change involves increasing the surveillance interval to 30 months (24 months + 25%) and is associated with plant changes to support 24 month fuel cycle implementation. The valves tested by T/S 4.7.3.b are listed in Attachment 1.

SECTION IIA - OPEN ITEMS DESCRIPTION *(Remove when resolved)*

There are approximately 120 MOV's throughout the plant. There are two off-line MOV preventative maintenance items performed at intervals of 36 months or more (multiples of an 18 month refueling interval) which will be impacted by the move to a 24 month fuel cycle. These include:

(1) Limitorque Actuator Inspections (RF02)

(2) EQ maintenance for Limitorque operated valves (RF03)

These surveillances are summarized in Table 1 with their current frequency and the associated performance interval in months for both a 18 month and 24 month cycle length. Based on conversations with the MOV system engineer, a new recommended performance frequency is included which is closest to the performance interval (in months) the system engineer recommended for each surveillance. Because the current practice is to perform each surveillance on only a portion of the approximately 120 MOV's during each outage (for example, half for RF02 items, one third for RF03 items, etc.) there will be some impact on the work scope required during a 24 month cycle outage which may either increase the outage length or require more manpower to complete with no change in length. These factors will have to be evaluated in the context of the whole 24 month fuel cycle project. One option which may help mitigate these

factors is the trend towards increased on-line performance of surveillance items. The MOV system engineer indicated they are moving in that direction.

PM Description	Current Frequency	Current Interval for Various Cycle Lengths: 18 Month Cycle (+25%)	24 Month Cycle (+25%)	Recommended New Frequency for 24 Mo Cycle
Limitorque Actuator Inspection	RF02	36-44 Mos	48-60 Mos	RF01 (24-30 Mos)
EQ Maintenance for Limitorque Valves	RF03	54-66 Mos	72-90 Mos	RF02 (48-60 Mos)

Table 1

SECTION III - EVALUATION OF CHANGE

The PCC system supplies cooling water for the following components which are needed for plant operation or to satisfy one or more basic safety functions: i.e., to maintain core hat removal, to maintain coolant inventory, etc.:

Containment Spray (CBS) pumps
Containment Spray Heat Exchangers
Residual Heat Removal (RHR) Pumps
RHR Heat Exchangers
Safety Injection (SI) Pumps
Centrifugal Charging Pumps
Containment Enclosure Coolers
Reactor Coolant Pump (RCP) Thermal Barrier Cooling Heat Exchangers

The PCC system consists of the RCP Thermal Barrier (RCPTB) loop and two independent flow loops, A and B, each of which supplies component cooling water to one of the redundant components performing engineered safeguard functions and to the RCPTB loop and to various nonsafeguard components. One of the two 100 percent (accident conditions) PCC pumps connected in parallel supplies flow to each loop. One PCC heat exchanger in loop A and one in loop B transfers the heat loads from the RCPTB loop and plant components to the Service Water System.

A single PCC loop A or B pump providing flow to the PCC heat exchanger in its loop is capable of removing the total heat during the recirculation phase following a loss-of-coolant accident occurring simultaneously with a loss of offsite electrical power.

The following factors related to PCC automatic valve performance over the last three operating cycles were considered in evaluating the extension of the surveillance frequency to a maximum of 30 months:

- Potential System Failure Modes
- Surveillance results
- Corrective maintenance frequency and type
- Preventative maintenance records
- System Engineer consultation

Potential System Failure Modes: Technical Specification Surveillance Number 4.7.3.b tests that the PCC valves automatically actuate upon receiving an Engineered Safety Feature signal. Potential modes of failure for this surveillance such as valve, sensor, or signal path failure do not have time dependent failures that are so short that they would be expected to occur inside of 30 months, or individual failures can be identified during plant operation through other surveillances which are performed on-line on a more frequent basis. The following provides a discussion of these items.

Valve Failure: Valves are tested on-line on a more frequent basis to confirm their operability or do not have failure modes that would be expected to occur inside of 30 months.

The four Motor Operated Valves (MOV) tested by T/S surveillance number 4.7.3.b are stroked monthly to check flow through the RHR heat exchangers. They are also time stroked quarterly. Periodic stroking ensures electrical power is available to the valve and identifies any valve mechanical problems. A review of the performance and trend of the quarterly stroke times of the MOV's showed no time dependent degradation in stroke times and continued proper mechanical performance thus supporting an increase in the T/S surveillance interval to at least 30 months. Periodic inspection and lubrication of these valves is performed at 36 month intervals and will not be impacted by a 30 month maximum test interval.

Piston operated valves CC-V32 and CC-V445 (Spent Fuel Pool Heat Exchanger Isolation) tested by T/S surveillance number 4.7.3.b are time stroked quarterly to confirm their operability. The quarterly time stroking ensures electrical power is available to the valve and identifies any valve mechanical problems. A review of the performance and trend of valve stroke times of these piston operated valves showed no time dependent degradation in stroke times and continued proper mechanical performance and thus supports an increase in the T/S surveillance interval to at least 30 months.

The remaining 13 valves are all piston operated valves and are only mechanically stroked as part of T/S surveillance number 4.7.3.b. A detailed review of historical stroke times of these valves was conducted to confirm that electrical power was always available to the valves and that valve stroke times were not time dependent on the interval of concern. Valve stroke times were reviewed following the initial 12 month refueling cycle and compared to valve stroke times following the two 18 month refueling cycles. Valve stroke times were completely independent of the interval between stroking. Additionally, all of the stroke times were significantly less than the

design basis maximum allowed stroke times. Environmental conditions in the vicinity of these valves were also deemed to have a minimal impact on valve performance from the current test interval out to the maximum test interval of 30 months. Therefore, although these 13 valves are not tested by any other surveillance in the interim between T/S surveillance 4.7.3.b performance, historical test data, environmental conditions, and no time dependent failure modes inside of 30 months support safe extension of the T/S surveillance interval to a maximum of 30 months on these valves.

Signal Path Failure: The signal path from the instrument to the valves is tested quarterly. The quarterly signal path tests confirm that the signal path can safely support the T/S surveillance interval extension to a maximum of 30 months.

Transmitter failure: The transmitters are calibrated at refueling intervals. Redundant transmitter channels feed each signal path. A transmitter failure inside of its calibration interval would be identified by operating logs review and by comparison to the other redundant instrument channels.

The potential failure mode review shows that, with the exception of the 13 piston operated valves, the entire system is tested on a significantly more frequent basis than T/S 4.7.3.b. Historical operating data on the 13 piston operated valves indicates with a high degree of confidence that these valves will perform their intended functions at intervals of 30 months. In combination, this information shows that there is an insignificant increase in risk by extending the surveillance interval to a maximum of 30 months.

Surveillance Results: Past surveillance test results were reviewed. The surveillance is verified by an integrated system test performed by procedure number EX1804.024 Revision 3 (Reference 1). The system design features worked correctly on all past surveillance tests (Attachment 2). Therefore, past surveillance tests support increasing the surveillance interval to 30 months (24 months +25%).

Corrective Maintenance Frequency and Type: PCC system corrective maintenance records were reviewed (Attachment 3). 54 of the 80 items were identified and corrected prior to initial plant operations at 100% power. An additional 10 items were design enhancements to the system, leaving only 16 system corrective maintenance items during the four operating cycles. During the plant's operating history there were no corrective maintenance items performed whose failures were time dependent. Additionally, none of the items for which corrective maintenance was performed would have prevented the valves from performing their design safety function upon receipt of an ESF signal. Therefore, corrective maintenance records support surveillance extension to 30 months (24 months +25%).

Preventative Maintenance Records: Review of the PCC system regularly scheduled preventative maintenance (PM) activities with a refueling or 18 month interval has concluded that there are no PM's with this interval. All off-line maintenance items have performance intervals, in years or refueling multiples, which are greater than 30 months (Attachment 4). Therefore, an increase in the T/S surveillance interval to a maximum of 30 months will not impact regularly

scheduled PM's on the PCC system, *assuming that all the open items listed in section IIA are resolved.*

System Engineer Consultation: The PWR PCC System Engineer and the PWR Motor Operated Valve Engineer were consulted to verify that the conclusions reached in this evaluation are consistent with their knowledge base. The system engineers confirmed that the PCC system performance history supports extension of the surveillance interval to 30 months.

SECTION IV -SIGNIFICANT HAZARDS EVALUATION

In accordance with 10CFR50.92, the utility has reviewed the proposed changes and has concluded that they do not involve a significant hazards consideration (SHC). The basis for this conclusion is that the three criteria of 10CFR50.92(c) are not compromised. The proposed changes do not involve an SHC because the changes would not:

1. Involve a significant increase in the probability or consequences of an accident previously evaluated.

The proposed change to Surveillance Requirement 4.7.3.b of the PWR's Technical Specifications extends the interval for verifying that each automatic valve servicing safety-related equipment actuates to its correct position on its associated Engineered Safety Features (ESF) actuation signal. The proposal would extend the interval from at least once per 18 months/refueling to at least once each refueling interval (nominal 24-months + 25% = 30 months).

The proposed change does not alter the intent or method by which the surveillance is conducted, does not involve any physical changes to the plant, does not alter the way any structure, system, or component functions, and does not modify the manner in which the plant is operated. As such, the proposed change in the interval of Surveillance Requirement 4.7.3.b will not degrade the ability of the PCC system to perform its safety function. Also, the PCC system is designed to perform its intended safety function even in the event of a single failure.

Equipment performance over the last three operating cycles was evaluated to determine the impact of extending the interval of Surveillance Requirement 4.7.3.b. This evaluation included a review of surveillance results, preventive maintenance records, and the frequency and type of corrective maintenance. It concludes that the PCC automatic valves are highly reliable, and that there is no indication that the proposed extension could cause deterioration in the condition or performance of any of the subject PCC components.

Since the proposed change only affects the surveillance interval for systems that are used to mitigate accidents, the change cannot affect the probability of any previously analyzed accident. While the proposed change can lengthen the interval between surveillances, the increase in interval has been evaluated and it is concluded that there is no significant impact on the reliability or availability of these systems and therefore, there is no impact on the consequences on any analyzed accident.

2. Create the possibility of a new or different kind of accident from any accident previously evaluated.

The proposed change to Surveillance Requirement 4.7.3.b of the PWR's Technical Specifications extends the interval for verifying that each automatic valve servicing safety-related equipment actuates to its correct position on its associated Engineered Safety Features (ESF) actuation signal. The proposal would extend the interval from at least once per 18 months/refueling to at least once each refueling interval (nominal 24-months + 25% = 30 months).

The proposed change does not alter the intent or method by which the surveillances are conducted, does not involve any physical changes to the plant, does not alter the way any structure, system, or component functions, and does not modify the manner in which the plant is operated. As such, the proposed change cannot create the possibility of a new or different kind of accident from any previously evaluated.

3. Involve a significant reduction in a margin of safety.

The proposed change to Surveillance Requirement 4.7.3.b of the PWR's Technical Specifications extends the interval for verifying that each automatic valve servicing safety-related equipment actuates to its correct position on its associated Engineered Safety Features (ESF) actuation signal. The proposal would extend the interval from at least once per 18 months/refueling to at least once each refueling interval (nominal 24-months + 25% = 30 months).

The proposed change to the surveillance interval is still consistent with the basis for the interval and the intent or method of performing the surveillance is unchanged. Further, the entire system from detectors to valves is either tested on a more frequent basis than T/S 4.7.3.b to confirm its operability or previous history of reliability of the PCC system provides assurance that the changes will not affect the reliability of the PCC system. Thus, it is concluded that there is no impact on the margin of safety.

SECTION V - REFERENCES

1. Procedure EX1804.024 Revision 3, dated 2/10/94

2. Primary Component Cooling System Design Basis Documentation, Revision 1, dated 1/4/95

3. Drawing Numbers 1-CC-D20205 to 1-CC-D20215

4. Updated FSAR Section 9.2.2, Revision 3.

5. Primary Component Cooling System Annual Performance Reports, 1990-1994.

6. Equipment Qualification Manual (SSEQ), Revision 6, dated dated 10/18/94.

7. Harsh Environment Equipment List (1-NHY-300218), Revision 9, dated 7/27/95.

8. Environmental Qualification of Electrical Equipment. EQ File 248-45-01, Revision 2, dated 7/27/89.

9. Operational Test Procedure OX1412.02, PCCW Quarterly Operability Test and 18 Month VPI Test. Revision 6, Change 4, dated 7/3/95.

ATTACHMENT 1
PWR TECHNICAL SPECIFICATION 4.7.3.b
Primary Component Cooling Water
Automatic Valve Surveillance Interval
Components Tested

Description	Valve Number	ESF Signal	Position
Train A			
PCC Isolation to Spent Fuel Pool Hx	CC-V32	Phase A	Open to Close
PCC Isolation to Containment (IC)	CC-V57	Phase B	Solenoid Energized Open to Close
PCC Isolation from Containment (IC)	CC-V121	Phase B	Solenoid Energized Open to Close
PCC Isolation from CBS Hx "A"	CC-V137	CBS	Close to Open
PCC Isolation from RHR Hx "A"	CC-V145	Phase A	Close to Open
PCC Isolation to Containment (OC)	CC-V175	Phase B	Solenoid Energized Open to Close
PCC Isolation from Containment (OC)	CC-V257	Phase B	Solenoid Energized Open to Close
PCC Isolation from Letdown Hx	CC-V341	Phase A	Solenoid Energized Open to Close
PCC Isolation to WPB	CC-V426	Phase A	Open to Close
PCC Isolation from WPB	CC-V427	Phase A	Open to Close
Train B			
PCC Isolation from Containment (OC)	CC-V122	Phase B	Solenoid Energized Open to Close
PCC Isolation to Containment (OC)	CC-V168	Phase B	Solenoid Energized Open to Close
PCC Isolation to Containment (IC)	CC-V176	Phase B	Solenoid Energized Open to Close
PCC Isolation from Containment (IC)	CC-V256	Phase B	Solenoid Energized Open to Close
PCC Isolation from CBS Hx "B"	CC-V266	CBS	Close to Open
PCC Isolation from RHR Hx "B"	CC-V272	Phase A	Close to Open
PCC Isolation to Spent Fuel Pool Hx	CC-V445	Phase A	Open to Close
PCC Isolation to WPB	CC-V447	Phase A	Open to Close
PCC Isolation from WPB	CC-V448	Phase A	Open to Close

Key: CBS - Containment Building Spray   IC - Inside Containment
WPB- Waste Process Building   OC- Outside Containment
RHR- Residual Heat Removal

ATTACHMENT 2
PWR TECHNICAL SPECIFICATION 4.7.3.b
Primary Component Cooling Water
Operations Surveillance History

System	Technical Specification	Procedure No.	Date Tested (completely)	Description	Comments
PCC	4.7.3.b	EX1804.024	9/30/91	Train A Auto Phase A, B, CBS 18 Month Surveillance Test	All valves tested satisfactory
PCC	4.7.3.b	EX1804.024	10/26/92	Train A Auto Phase A, B, CBS 18 Month Surveillance Test	All valves tested satisfactory
PCC	4.7.3.b	EX1804.024	7/7/94	Train A Auto Phase A, B, CBS 18 Month Surveillance Test	All valves tested satisfactory
PCC	4.7.3.b	EX1804.024	9/20/91	Train B Auto Phase A, B, CBS 18 Month Surveillance Test	All valves tested satisfactory
PCC	4.7.3.b	EX1804.024	11/01/92	Train B Auto Phase A, B, CBS 18 Month Surveillance Test	All valves tested satisfactory
PCC	4.7.3.b	EX1804.024	7/7/94	Train B Auto Phase A, B, CBS 18 Month Surveillance Test	All valves tested satisfactory

ATTACHMENT 3
PWR TECHNICAL SPECIFICATION 4.7.3.b
Primary Component Cooling Water
Corrective Maintenance History

System	Component	Failure/Maintenance Activity	RTS Number and Date Repaired	Impact on Plant Operations	Comments
PCC	CC-V32	Seat leakage	87W007913 1/15/88	None	Installed new seal ring and backup ring. Retest sat.
PCC	CC-V32	Rework Raychem splice	88W004058 1/23/89	None	Performed Raychem installation.
PCC	CC-V32	Modify jack screws	88W004656 1/27/89	None	Modified jack screws.
PCC	CC-V32	Rework cable splices	89W001514 9/15/89	None	Installed new Raychem splice kits.
PCC	CC-V32	Replace Tefzel seals in Posiseal valves	91W001150 9/3/91	None	Replaced existing Tefzel seal with new EPR seal.
PCC	CC-V57	Air filter polycarbonite bowl is cracked and leaking air	88W004149 1/28/89	None	Replaced polycarbonite bowl. Retest sat.
PCC	CC-V57	Rework cable splices	89W001509 9/15/89	None	Reworked splices.
PCC	CC-V121	Air filter polycarbonite bowl is cracked and leaking air	88W004233 2/23/89	None	Replaced polycarbonite bowl. Retest sat.
PCC	CC-V121	Valve fails to open from the main control board.	89W003616 1/8/90	None	Replaced broken wire to solenoid. Retest sat.
PCC	CC-V121	Air to solenoid is leaking at outlet.	94W001792 5/23/94	None	Replaced tubing. Retest sat.

System	Component	Failure/Maintenance Activity	RTS Number and Date Repaired	Impact on Plant Operations	Comments
PCC	CC-V122	Air leak at swage elbow connection.	87W005961 6/4/88	None	Replaced fitting. Retest sat.
PCC	CC-V122	Valve failed type "C" leak test.	87W005961 6/23/88	None	Disassembled valve. Cleaned all parts. Assembled with new seal. Retest sat.
PCC	CC-V122	Threads on gagging handwheel are stripped.	88W003350 7/21/88	None	Replaced handwheel and end cap. Retest sat.
PCC	CC-V122	Air regulator leaking at relief port/vent.	89W000898 4/7/89	None	Replaced regulator. Replaced bent nipple at valve end. Retest sat.
PCC	CC-V122	O-ring is pinched between piston cover.	89W000897 3/23/89	None	Removed damaged o-ring and replaced. Retest sat.
PCC	CC-V122	Rework cable splices.	89W001523 9/26/89	None	Reworked splices.
PCC	CC-V137	Housing cover gasket leaking oil.	87W007796 1/14/88	None	Gasket replaced. Retest sat.
PCC	CC-V137	Auxiliary switches misaligned.	88W003100 3/10/88	None	Properly installed misaligned auxiliary switch.
PCC	CC-V137	Inspect cable connection.	88W003613 3/13/88	None	Stripped old Raychem from cable and installed new Raychem.
PCC	CC-V137	Grease leaking from local position indicator.	88W004749 1/20/89	None	Cleaned valve and tightened fill plug.
PCC	CC-V137	Valve shows 5% open locally when MCB indicates shut.	91W004628 9/18/91	None	Adjusted local dial pointer to correct position.
PCC	CC-V137	Replace Tefzel seals in Posiseal valves	91W001150 8/13/91	None	Replaced existing Tefzel seal with new EPR seal.

System	Component	Failure/Maintenance Activity	RTS Number and Date Repaired	Impact on Plant Operations	Comments
PCC	CC-V137	Rework VPI	91W000952 8/11/91	None	Readjusted limit by-pass switch, replaced cracked limit sw rotor.
PCC	CC-V137	Flange leak.	91W004720 4/15/94	None	Torqued flanges. Minor leakage. Replaced gaskets during RF03.
PCC	CC-V145	Valve will not move off shut seat from MCB.	87W003965 5/27/87	None	Thorough inspection, measurements and retests sat. Could not duplicate.
PCC	CC-V145	Inspect cable.	88W003612 3/13/88	None	Covered by Raychem. Relugged shielded wire.
PCC	CC-V145	Flange leak.	88W006119 7/13/89	None	Removed valve. Replace gaskets and retorqued.
PCC	CC-V145	Lubricant leaking at VPI housing.	91W001915 8/21/91	None	Cleaned lubricant. Tightened screws on cover.
PCC	CC-V145	Replace Tefzel seals in Posiseal valves	91W001134 9/3/91	None	Replaced existing Tefzel seal with new EPR seal.
PCC	CC-V145	Rework VPI.	91W000950 8/11/91	None	Reworked VPI per DCR 89-024. All retests sat.
PCC	CC-V145	Flange leak	89W004430 8/24/91	None	Removed valve. Flanges out of parallel by 3/16". Retorqued. Flanges still leak 2 drops/min.
PCC	CC-V145	Chronic flange leak.	94W000121 4/20/94	None	Replaced flange joint. Flange still leaks. Will correct with new 1/4" gasket during RF04.
PCC	CC-V168	Replace Tefzel seals in Posiseal valves	86W008862 1/8/87	None	Replaced existing Tefzel seal with new EPR seal.

System	Component	Failure/Maintenance Activity	RTS Number and Date Repaired	Impact on Plant Operations	Comments
PCC	CC-V168	Acme threads stripped on air actuator.	87W005717 7/6/87	None	Replaced handwheel and end cap. Retest sat.
PCC	CC-V168	Internal spring to manual handwheel broken.	87W005717 7/6/87	None	Replaced spring. Retest sat.
PCC	CC-V168	Butterfly valve binding.	91W004080 8/21/91	None	Rebuilt actuator. Tested sat. Cause of binding unknown.
PCC	CC-V175	Modify jack-screws.	89W000532 2/13/89	None	Modified jack-screws per DCR 87-414. Retests sat.
PCC	CC-V175	Rework splices.	89W001522 11/13/89	None	Reworked splices with Raychem kits.
PCC	CC-V176	Modify jack-screws.	89W000532 2/13/89	None	Modified jack-screws per DCR 87-414. Retests sat.
PCC	CC-V176	Replace Tefzel seals in Posiseal valves	86W008862 1/8/87	None	Replaced existing Tefzel seal with new EPR seal.
PCC	CC-V176	Rework splices.	89W001522 11/13/89	None	Reworked splices with Raychem kits.
PCC	CC-V256	Modify jack-screws.	89W000532 2/13/89	None	Modified jack-screws per DCR 87-414. Retests sat.
PCC	CC-V256	Air blowing by seal on handwheel.	87W004577 5/4/88	None	Handwheel removed and teflon seal replace. Retest sat.
PCC	CC-V256	Polycarbonite bowl is cracked and leaking air.	88W004148 10/1/88	None	Replace bowl. Retest sat.
PCC	CC-V256	Replace Tefzel seals in Posiseal valves	86W008862 1/8/87	None	Replaced existing Tefzel seal with new EPR seal.

System	Component	Failure/Maintenance Activity	RTS Number and Date Repaired	Impact on Plant Operations	Comments
PCC	CC-V257	Modify jack-screws.	89W000532 2/13/89	None	Modified jack-screws per DCR 87-414. Retests sat.
PCC	CC-V257	Replace Tefzel seals in Posiseal valves	86W008862 1/8/87	None	Replaced existing Tefzel seal with new EPR seal.
PCC	CC-V257	Rework splices.	89W001513 9/15/89	None	Reworked splices with Raychem kits.
PCC	CC-V266	Auxiliary switches misaligned	88W003145 7/27/88	None	Aligned switches.
PCC	CC-V266	Handwheel cover leaking oil.	88W001503 9/6/88	None	Tightened drive sleeving housing cover. Retest sat.
PCC	CC-V266	Replace Tefzel seals in Posiseal valves	91W001219 8/22/91	None	Replaced existing Tefzel seal with new EPR seal.
PCC	CC-V266	Rework VPI.	91W000953 8/13/91	None	Reworked VPI. Retests sat.
PCC	CC-V272	Auxiliary switches misaligned	88W003144 7/27/88	None	Aligned switches.
PCC	CC-V272	Oil leaking from motor T-drain.	91W000545 8/31/91	None	Tightened bolts. No leakage noted.
PCC	CC-V272	Replace Tefzel seals in Posiseal valves	91W001221 8/16/91	None	Replaced existing Tefzel seal with new EPR seal.
PCC	CC-V272	Rework VPI.	91W000951 8/16/91	None	Reworked VPI. Retests sat.
PCC	CC-V341	Rework Raychem splice.	88W004059 9/19/88	None	Reworked splice.
PCC	CC-V341	Slide link at MCB damaged due to arcing	90W006115 9/26/92	None	Lifted leads and replaced terminal block during RFO2.

System	Component	Failure/Maintenance Activity	RTS Number and Date Repaired	Impact on Plant Operations	Comments
PCC	CC-V341	Replace Tefzel seals in Posiseal valves	91W001154 4/14/94	None	Replaced existing Tefzel seal with new EPR seal.
PCC	CC-V426	Rework cable splices	89W001516 9/15/89	None	Reworked splices.
PCC	CC-V426	Replace Tefzel seals in Posiseal valves	91W001152 8/12/91	None	Replaced existing Tefzel seal with new EPR seal.
PCC	CC-V426	Packing leak.	92W004468 10/26/92	None	Tightened gland bolts. Leakage stopped. Cycled valve sat.
PCC	CC-V427	Rework cable splices	89W001516 9/15/89	None	Reworked splices.
PCC	CC-V427	Packing leak.	89W005702 12/14/89	None	Torqued gland bolts. Leakage stopped. Cycled valve sat.
PCC	CC-V427	Replace Tefzel seals in Posiseal valves	91W001146 8/12/91	None	Replaced existing Tefzel seal with new EPR seal.
PCC	CC-V445	Rework cable splices	89W001525 9/12/89	None	Reworked splices.
PCC	CC-V445	Packing leak.	92W005465 12/14/89	None	Torqued gland bolts. Leakage stopped. Cycled valve sat.
PCC	CC-V445	Replace Tefzel seals in Posiseal valves	91W001126 9/7/91	None	Replaced existing Tefzel seal with new EPR seal.
PCC	CC-V445	Limit switch cycling when valve closed.	92W002705 2/12/93	None	Removed limit switch and cleaned dirty contacts. Retest sat.
PCC	CC-V447	Seat leakage.	87W000947 12/7/87	None	Replaced seal ring, repacked valve. NOP retest sat.
PCC	CC-V447,448	Valves leak by.	89W000567 2/14/89	None	Inspected seats and discs, minor scratches cleaned.

System	Component	Failure/Maintenance Activity	RTS Number and Date Repaired	Impact on Plant Operations	Comments
PCC	CC-V447,448	Continued leak by	89W000789 3/8/89	None	Adjusted arms on closed limit switches. Retests sat.
PCC	CC-V447,448	Leak checks	89W001288 3/28/89	None	Determined leak rate sat on 448, unsat on 447.
PCC	CC-V447	Disassemble and inspect valve for seat leakage problem.	89W001328 5/17/89	None	Disc not seating properly on seat. Worked valve. Retests sat.
PCC	CC-V447	Replace Tefzel seals in Posiseal valves	91W001123 8/20/91	None	Replaced existing Tefzel seal with new EPR seal.
PCC	CC-V447	Rework cable splices	89W001526 10/28/89	None	Reworked splices.
PCC	CC-V448	Packing leak.	87W007225 1/18/88	None	Torqued packing gland bolts. Retests sat.
PCC	CC-V448	Seat Leakage	87W007225 11/23/87	None	Replace seal ring, torqued flange bolts. Inservice leak test sat.
PCC	CC-V448	Replace Tefzel seals in Posiseal valves	91W001124 8/15/91	None	Replaced existing Tefzel seal with new EPR seal.
PCC	CC-V448	Rework cable splices	89W001527 10/28/89	None	Reworked splices.

ATTACHMENT 4
PWR TECHNICAL SPECIFICATION 4.7.3.b
Primary Component Cooling Water
Off-Line Automatic Valve Preventative Maintenance

PM Description	Frequency	Procedure
Inspect/Rebuild Valve Actuator	Special - As Required	IS0602.910
Limitorque Actuator Inspection	RF02/RF03	LS0569.01
EQ maintenance for Limitorque operated valves	RF03	LS0569.09
EQ maintenance (NAMCO limit switches)	8/12/19 yr	LS0564.19
EQ maintenance (ASCO solenoid valves)	37 yr	IS0603.005

Note: RF refers to a refueling interval. The number following indicates the frequency of performance. For example, RF02 is performed every second refueling.

Chapter 6 - A Framework for Reducing Forced Outage Rates

6.1 Introduction

The primary focus of this thesis is the development and application of a strategy for resolving a power plant's surveillance program to minimize refueling and planned maintenance outage times during extended fuel cycles. In doing this, the two primary goals of the thesis were met. The thesis demonstrated that, with the exception of the Category C surveillances of Chpater 4, the regulatory and investment protection barriers to extended cycle lengths perhaps can be overcome, and it provided a systematic surveillance resolution procedure that utilities can use to prepare for extended cycle lengths. The two other key issues discussed in Chapter 1 that must be addressed to make extended fuel cycles attractive to the nuclear industry are increasing the cycle length between refuelings through improved core designs, and reducing forced outages rates.

Forced outages, as defined here, include any unplanned outages during an operating cycle. This includes plant trips and short term controlled shutdowns to complete any unexpected repairs. Forced outages are primarily caused by either equipment failure or human error. The impact of human error on forced outages is difficult to quantify but has been estimated to account for as much as 20% of the overall forced outage rate.[14] This is because many forced outages which on the surface appear to be due to component failure actually have human error as their root cause. For example, a plant trip caused by a loss of a main feed pump governor control valve will often be reported as a main feed pump failure. Yet, further investigation of the failure might show that the governor system failed because the wrong type of fastener was used in assembling the governor during the last outage. So although an equipment failure caused the forced outage, the fact that the mechanical failure was caused by improper maintenance means that the forced outage was in reality caused by human error. The distinction is vitally important when attempting to reduce the forced outage rates for extended fuel cycles. Since the possibility of human error always exists, increasing the number or frequency of surveillances or maintenance items will

[14] Conversation with Dr. Chong Chiu, San Onofre, June 1995 at the MIT Summer Reactor Safety Seminar.

always tend to increase the forced outage rate due to human error. Conversely, reducing the number and frequency of surveillances or maintenance items will reduce the forced outage rates due to human error. The key then is to determine the optimum types and frequency of surveillances and maintenance such that the combination of forced outage rates from equipment failure and human error are minimized. This topic will form the basis for significant future work.

Because quantifying and reducing the impact of human error on the plant force outage rate is extremely difficult, a different approach is taken towards the goal of reducing forced outages to less than 3%[15] (~40 days) during a 48 month fuel cycle. This approach focuses almost exclusively on understanding and reducing component root causes of failure as the best way to improve individual component reliability. By improving component reliability there will be an indirect reduction of the impact of human error on plant forced outage rates because more reliable equipment will require less maintenance and testing. Reducing the amount of maintenance and testing means less human involvement, and thus less chance of introducing human error. The question then that must be answered is "Can the component be expected to run reliably for at least 48 months with no maintenance which requires the component to be removed from service?" If the answer to that question is yes, then the interval between surveillances or maintenance is at least 48 months and the component will not pose a barrier to an extended fuel cycle.

Li and Golay[16] determined for the Condensate-Feedwater System that to achieve a 97% system capacity factor (3% forced outage rate), the overall independent component mean time to failure must be approximately 10^{-6}/hr or better if no repair time is considered as shown in figure 6-1 at point A. Figure 6-1 shows that if repair is also considered, and the average repair time is 1000 hours (~40 days) then the allowable failure rate of the component is 2×10^{-5}/hr as shown at point B. If average repair times are reduced to 100 hours (~4 days), then allowable component failure rate is 2×10^{-4}/hr as shown at point C. Therefore, if component failure rates are determined to be 10^{-6}/hr or better, no further improvements to the components performance is required to make it compatible with a 48 month fuel cycle. These analyses neglect the effects of common

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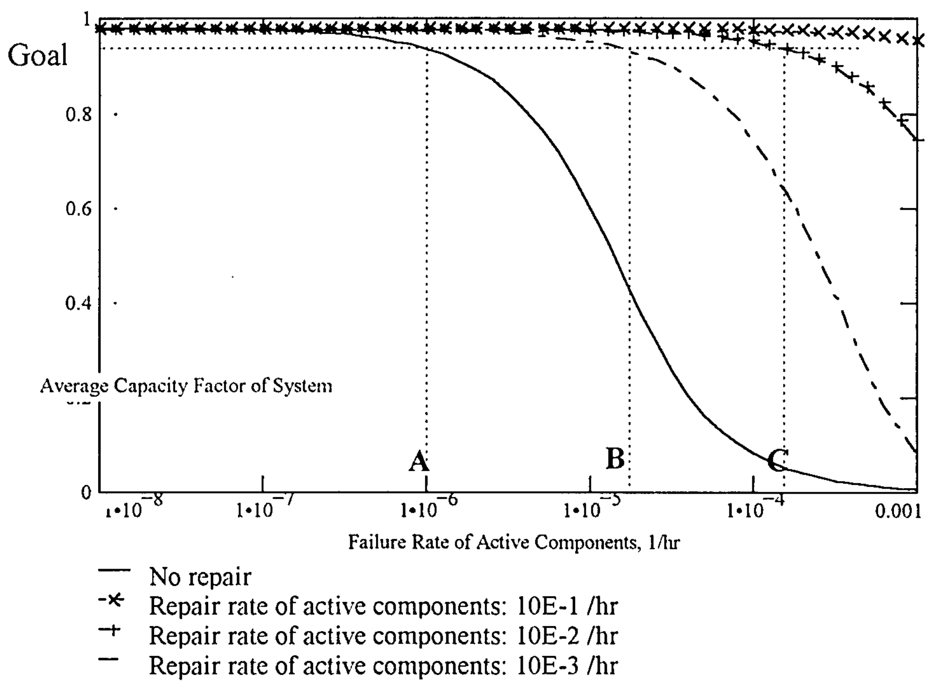
[15] The 3% goal is based on the probable U.S. utility industry forced outage rate taget for the year 2000.

[16] Golay, Michael, and Li, Feng, "Results Summary from Reliability Sensitivity Analysis for a PWR Condensate-Feedwater System", May 1996,

cause failure. For component failure rates which do not meet the 10^{-6}/hr target, two options exist to reach the 97% system capacity factor goal. First, the component could be improved to reach the 10^{-6}/hr failure rate target independent of repair, or second, the component failure rate and the average time to repair could both be improved so that in combination they meet the 97% system capacity factor goal. Both options should be explored in detail and the most economic plan chosen. Note that this study assumed that the rest of the plant did not contribute to the overall forced outage rate. Therefore, the actual failure rates needed to achieve a plant capacity factor of 97% will be somewhat higher than the values stated here.

Allowable Failure Rates of Active Components Needed to
Achieve a Component 97% Capacity Factor with Various Repair Times

Figure 6 - 1[17]



Because passive components such as heat exchangers are typically considered to have failure rates which are already at least 10^{-6}/hr or better, the components that should be examined first are components where:

[17] Li, Feng, and Golay, Michael, "Results Summary from Reliability Sensitivity Analysis for a PWR Condensate-Feedwater System", Department of Nuclear Engineering, Massachusetts Institute of Technology, May 1996, p. 16.

- Failure will result in a reactor trip or shutdown and where,
- No redundancy exists when the plant is operating at rated power

Fortunately, there are very few components at a typical PWR that meet these two criteria. These include the Reactor Coolant Pumps of which there are typically four per plant, the Main Turbine and Generator of which there is typically only one, the Main Feed Pumps (MFP) of which there are typically two, and selected portions of the Electrical Distribution and Reactor Protective Systems.

A 1994 study by Yankee Atomic entitled "Operational Reliability Analysis of Seabrook Station", November 1994, concluded from a review more than 900 Westinghouse NSSS system trip experiences between 1985 to mid-1993 that the following components or systems had the largest contribution to the overall plant forced outage rate and were the driving factors in overall plant reliability:

- Turbine Generator and Turbine Generator Controls
- Feedwater and Feedwater Controls
- Electrical Distribution
- Reactor Protection[18]

Because of these results, these types of components should be studied first in an overall strategy to reduced plant forced outage rates below 3%. The overall strategy for reducing forced outage rates must address the following key issues:

- Current component or system reliability levels
- Major component/system failure mechanisms and their root causes
- Current surveillance program's impact on overall component or system reliability

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[18] O'Regan, Patrick J., "Operational Reliability Analysis of Seabrook Station", Yankee Atomic Energy Corporation Contract 1880, November 1994. p. 23.

Of the components discussed previously, the MFP was chosen as the initial candidate to study in detail because of its relative simplicity and because of the access to data and the personnel necessary to conduct the research. This chapter begins the work necessary to answer the question of whether the MFP can be expected to run reliably without being shutdown for at least 48 months. It includes research on the root causes of MFP failures, as well as interviews with industry personnel, maintenance and diagnostic experts, pump consultants, vendors, and manufacturers of significant pump sub-systems such as mechanical seals. While not providing the final answer to the question of whether the MFP will run reliably for at least 48 months, this chapter lays the groundwork and direction for future work on the MFP as well as a framework for investigating other key plant components such as those mentioned in the preceding paragraph.

6.2 Estimates of Current Main Feed Pump Reliability

The first step in reducing forced outage rates is to determine as accurately as possible the current reliability levels of the component or system independent of repair. This is vital to understanding the component or systems contribution to the overall plant forced outage rate as well as providing a starting point for determining how much reliability improvement in the component or system is needed to meet the goal of an overall plant forced outage rate of no more than 3%.

The first step in determining the current reliability levels of the MFP was a review of Westinghouse Plant Licensee Event Reports (LER), written from 1985 to 1993, which reported the cause of plant shutdown as the Feedwater System. This review, conducted as part of a 1994 single component failure study at the candidate PWR found 250 LER's which reported the cause of plant shutdown as the Feedwater System. These 250 LER's were then further broken down by the author of this thesis. The event description of each LER was examined to determine the actual cause of the shutdown. Shutdowns caused by component failure which were the result of improper maintenance or installation were classified as human errors. Of the 250 Feedwater System LER's which caused shutdowns, 55 were attributable to the Main Feed Pump. These 55 LER's were further broken down by their root causes. The causes and the number of occurrences of each are shown in table 6-1.

LER Reported Causes of MFP Failures (1985-1993) Leading to Plant Trips

Table 6 - 1

Cause	Number
Shaft Failure	1
Turbine Failure	2
Motor Failure	3
Pressure Switch Failure Causing Pump Trip	5
Thrust Bearing Failure	3
Speed Control System	18
Lube Oil	15
Vibration	1
Valves Associated with Pump	7

There are 77 PWR plants in the United States. It was assumed that the plants on average had two MFP's each for a total of 144 pumps in the study. It was also assumed, based on discussions with plant engineers that MFP's were operational 75% of the time over the course of the nine years studied. Note that this 75% is not the plant capacity factor, but an estimate of the average operating time of the Main Feed Pump during the course of a year. Based on this information, a first estimate of the MFP failure rate was calculated.

MFP Failure Rate = 55 failures/(144 pumps*9 years*365.25d/yr*24hr/day*.75)

$6.46*10^{-6}$/hr

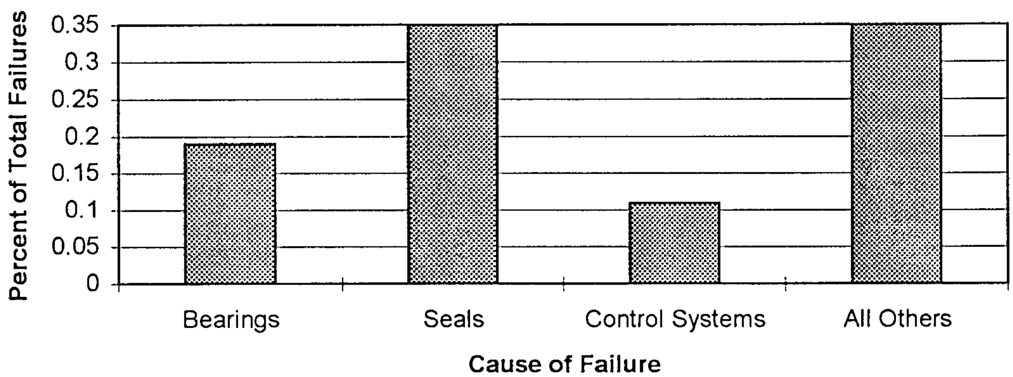
This initial estimate of the MFP failure rate is close to the value of 10^{-6}/hr needed to support the goal of a system 97% capacity factor assuming no repairs are considered. Improving the reliability of the MFP by a factor of about six is needed to meet the project goals assuming no repair. Although the case of no repair is artificial, it does provide an excellent target for improving component reliability. If a component's reliability can be economically improved to the point where it meets target capacity factor goals without repair, it will clearly support capacity factor goals if repair is allowed.

A second and possibly more accurate estimate of MFP failure rates was obtained through a search of the Nuclear Plant Reliability Data System (NPRDS). This search revealed 205 events

caused by MFP's that resulted in either a plant trip, plant shutdown, or a reduction in power. This data was over approximately the same time period as the LER trip history data, but includes all 110 licensed power plants (both PWR and BWR) in the United States. The leading causes of MFP failures from this search are as shown in Figure 6-2.

NPRDS Leading Causes of MFP Failures

Figure 6 - 2



Using the NPRDS results, one obtains an estimated failure rate of:

MFP failure rate = 205/(220 pumps*9 years*365.25d/yr*24hr/day*.75)

1.57×10^{-5}/hr

Although this failure rate is almost two and one-half times greater than the first calculated failure rate, it is important to remember that more than 75% of the MFP failures reported in the NPRDS system did not require the plant to be shutdown. Most of the repairs were conducted with the plants at powers ranging from 50% to 67%, depending on the number and capacity of the remaining pumps available. Thus, while the overall failure rate is somewhat higher, its overall impact on the plant capacity factor is probably smaller because the plants retain the capability to produce power during the course of many of these MFP repairs.

In order to get an estimate for the average outage times following a trip caused by a MFP failure, a review was conducted of the database maintained by the NRC which documents plant performance. From 1989 to mid-1995 there were a total of 24 forced outages industry-wide

caused by problems with a MFP. The average outage hours for these 24 events was 51.3 hours. Using this as an estimate of the average repair time for MFP failures and referring back to figure 6-1, one obtains an allowable MFP failure rate of about 3×10^{-4}/hr needed to achieve a system 97% capacity factor.

These initial estimates of the current MFP reliability demonstrate that the MFP reliability levels are probably already very close to the point where they could reliably support extended cycles of 48 months. The results of all these calculations are summarized in table 6-2 below. However, even though initial reliability estimates may demonstrate that a component could be expected to operate reliably over an extended cycle, further component reliability improvements should be pursued. The 3% forced outage goal is the upper limit on acceptable forced outage rates. If additional economic reliability improvements can be made to a component which will contribute to even lower forced outage rates, they should be strongly considered. Additionally, maximizing the reliability of individual components will also help offset the impact of any components whose reliability levels cannot be economically improved. Therefore, further sections in this Chapter will focus on the root causes of failures of MFP's and address some of the recommended design, installation, and operational techniques to improve MFP performance.

Summary of MFP Failure Rate Estimates

Table 6 - 2

Method	Failure Rate
LER Review of Main Feed Pump Trips (No Repairs Assumed)	6.46 E-6 (Calculated)
NPRDS Review of all MFP Trips, Shutdowns, Power Reductions (No Repairs Assumed)	1.57 E-5 (Calculated)
Allowable MFP Failure Rates Given a 50 Hour Average Repair Time	3.0 E-4 (Allowed)

6.3 Root Causes of Main Feed Pump Failures

6.3.1 Introduction

Based on the service requirements for main feed pumps used in the nuclear industry, they should exhibit very high reliability levels. Because nuclear power plants operate at much lower temperatures than fossil plants, very high steam flow rates are required to the turbine generators to deliver the steam energy necessary to produce large amounts of power, on the order of as much as 1200 MWe. These high mass flow rates result in the need for feed pumps which have very high capacity but much lower head requirements than those required for fossil plants. These requirements are typically met with a single stage, high capacity, high speed pump. Most plants use two 50% capacity pumps, with some of the older designs using three 50% pumps. The single stage pump means that the impeller shaft is shorter and thus the bearing spans are much closer than a typical fossil plant MFP. The shorter bearing spans typically mean more even load distributions on the bearings and thus longer life. The shorter shafts also mean that there is less flexing in the shaft, resulting in a lower likelihood of misalignment and vibration, two of the leading causes of impeller, bearing, or seal failures. Additionally, nuclear plants are most often operated at rated power as opposed to commercial fossil plants which are typically operated on a cycling or load following mode based on the local grids demand. Because of this, nuclear feed pumps should be able to operate for longer periods closer to their best efficiency point (BEP) as illustrated in figure 6-3 below.

Figure 6-3 shows the combination of flow and pump head which result in the pump operating at its Best Efficiency Point (BEP). Operating at the BEP is important not only because it represents the maximum hydraulic efficiency point, and thus requires the least energy to run the pump, but also because operations at this point are known to result in the most most efficient flow streams within the pump. The most efficient flow streams result in the lowest possible dynamic stresses in the pump and various pump components, lower risk of cavitation, and therefore longer lifetimes for pump components as well as reduced maintenance.[19]

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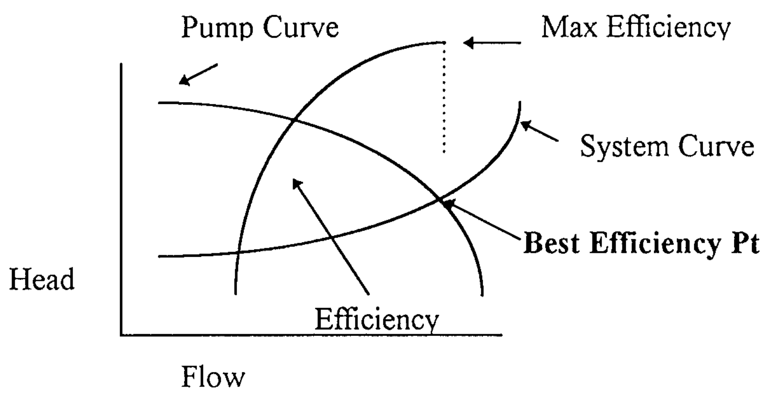
[19] Feedpump Operation and Design Guidelines - Summary Report. Prepared by Sulzer Brothers Limited, Winterthur, Switzerland for the Electric Power Research Institute. Final Report, June 1993., pgs. 1-7.

Main Feed Pump Operating Curves

Figure 6 - 3



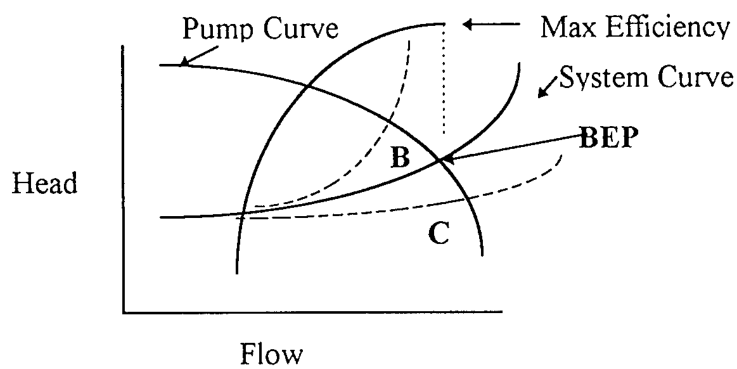
Given these inherent advantages, the MFPs used in the nuclear industry should exhibit significantly higher reliability levels than their fossil counterparts. However, in general this is not the case. The American Electric Power Company (AEPC), for instance, uses only one, multi-stage, 70,000 horsepower feed pump for their 1300 MWe fossil plant designs. These pumps which have historical availabilities of around 99% match or exceed the availabilities of most of the MFPs used in the nuclear industry. AEPC feed pumps must be reliable or their plants cannot operate, and they are.

The remaining portions of this chapter will focus on the major failure mechanisms exhibited by nuclear MFPs, their principal root causes, and some general recommendations for how to reduce the particular failure mechanism. Based on conversations with many pump experts ranging from vendors to plant engineers, most of the pump failure mechanisms and many of their root causes of failure are already fairly well understood. In many cases, there are also detailed recommendations for how to reduce these failures. However, the detailed understanding of the root causes of failures and potential solutions for their elimination does not appear to be incorporated into the day to day maintenance and operations of the pumps. Most importantly, despite all the knowledge that exists on pump design and operation, it does not appear that there has been a serious effort to make a quantitative connection between recommended solutions and subsequent improvements in pump reliability. For example, how much more reliably would a

MFP run if it was always operated at its best efficiency point (BEP)? What are the quantitative reliability trade-offs from operating to the left or right of the BEP as shown at points B and C on figure 6-4?

Other Main Feed Pump Operating Points

Figure 6 - 4



As another example, the industry today is using more and more sophisticated monitoring and diagnostic equipment to monitor feed pump performance. These new systems are estimated to cost about $50,000 per pump to install, not to mention the costs of training people in how to use the equipment. Yet, no one interviewed could conclusively say what the quantitative reliability gains would be from using this type of equipment. In an age of increased competition, utilities must understand the cost benefits of their engineering options. Quantifying the reliability gains from various options typically employed to improve pump reliability should form the basis for significant future study within the industry.

6.3.2 Major Failure Mechanisms and Root Cause Discussion

Figure 6-5 contains a simplified diagram which summarizes the principal failure mechanisms and their root causes for MFP's. The diagram was developed based on a review of NPRDS failure data, LER's, and discussions with experts in the main feed pump field. The number or letter associated with each box allows for a ready classification scheme that could be

applied to all MFP failures and placed in a database for analysis. For instance a MFP failure caused by seal leakage, where the seal failed due to vibration caused by an initial misalignment of the pump would be classified as A.1.a.i.

Two root causes which were not included in Figure 6-5 were failure due to normal wear and failure due to human error. These root causes accounted for 58 of the 205 (28%) MFP failures reported in NPRDS which resulted in a plant trip, shutdown, or power reduction. This includes 40 of 205 (19.5%) which were attributed to normal wear and 18 of 205 (8.7%) which were attributed to human error. However, based on a review of plant material history, pump maintenance schedules, and discussions with pump experts, it is likely that the expected lifetime of components such as bearings, seals, pump impellers, and wearing rings, subject to normal wear is well in excess of 48 months and therefore should not adversely impact on pump reliability levels during a 48 month cycle. Also, as noted in the beginning of this chapter, this study does not attempt to correct failures resulting from human error with the exception of that by reducing the maintenance intervals of plant components, that part of the total failure rate due to human error is reduced.

6.3.2.1 Major Failure Mechanisms

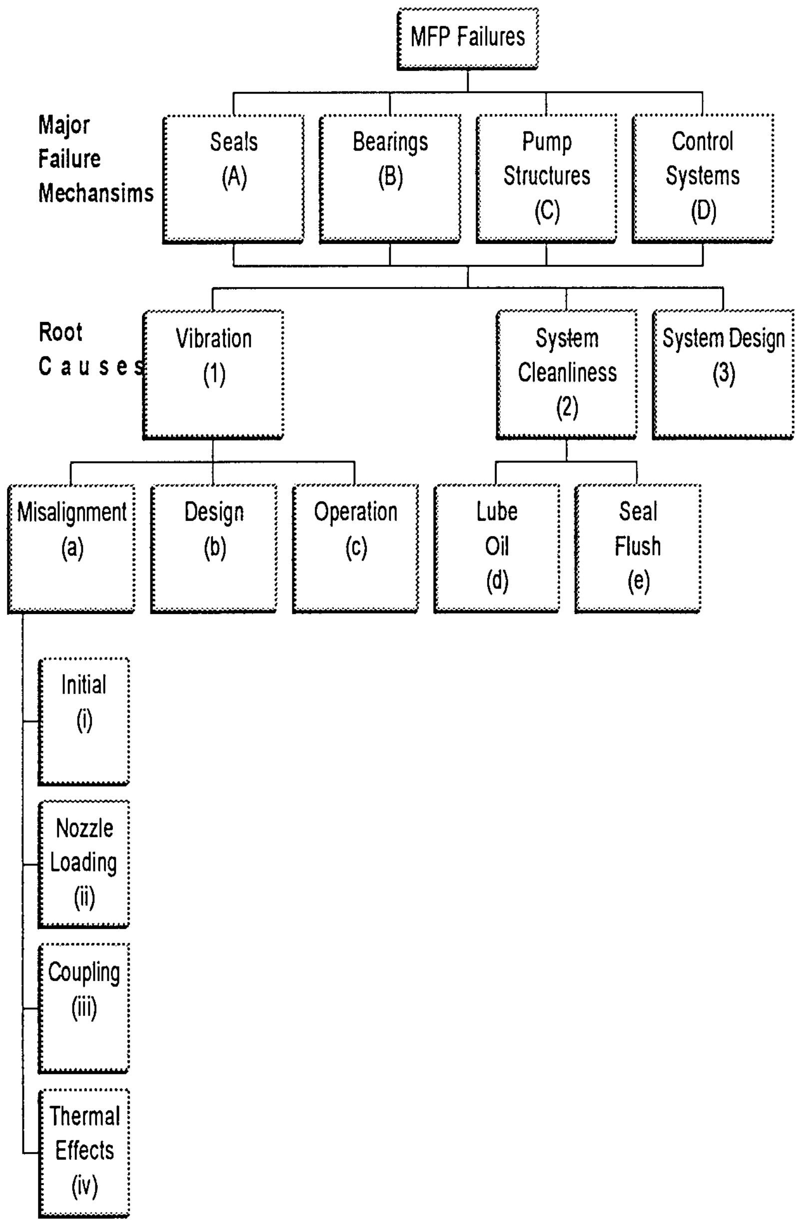
6.3.2.1.1 Seals

Seal failures accounted for the largest number of MFP reported failures. Of the 205 reported MFP failures, 70 were caused by seal failures. Seal failures were reported as being most often caused by improper installation, misalignment, vibration, material deficiencies, and debris injected into the seal. By far, the largest contributor to seal failure was dirt or debris injected into the seal area resulting in scoring or clogging of the seal area. The scoring of the seal results in uneven pressure distributions across the seal faces which ultimately leads to leakage. Debris in the seal area can also reduce the amount of cooling water to the seals resulting in seal overheating, distortion, damage, and ultimately leakage. Maintaining clean flush water at the proper pressures and flow is vital to long term seal performance.

Two of the major seal types used on feed pumps are throttle bushing seals and mechanical seals. Throttle bushings are used on most fossil industry MFPs and some PWR MFPs. They

Main Feed Pump Failure Diagram

Figure 6 - 5



have a history of very reliable long-term performance but have several disadvantages. First, they generally have much higher leak rates than mechanical seals and may require special drains. The leakage results in larger makeup quantities of expensive feedwater. They also require close clearances which are difficult to achieve and therefore costly. Finally, for nuclear power plants, the leakage, especially at Boiling Water Reactors, may be a radiological concern. At most PWR's, throttle bushing leakage is more a makeup water concern than it is a radiological concern.

Mechanical seals come in a variety of designs. The major advantage of mechanical seals is that they are relatively leak free. Mechanical seals have a wide variety of applications and are widely used in the chemical and oil industry where pumps are required to pump fluids which are very dangerous to humans and the environment and for which little to no leakage can be allowed. They are often used in Boiling Water Reactors, where the water in the feed system is contaminated and less leakage is allowed. They are also used in many instances in PWR MFPs. Based on discussions with a leading seal manufacturer, mechanical seals have a typical service life of six to eight years when installed properly and operated under design conditions. The most common type of seals used for feed pump applications are balanced, pusher, rotating seat seals. A rotating seal face of antimony filled carbon bearing upon reaction bonded silicon carbide offers the best combination of seal wear, corrosion characteristics, and thermal conductivity.[20]

A survey of seal failures in the United States by one of the world's largest seal manufacturers[21] found that the principal causes of mechanical seal failures were:

- 40% Operational Problems - caused by items such as flow interruptions
- 24% Mechanical Difficulties - caused by assembly errors, incorrect clearances, inadequate alignment
- 19% Faulty Fluid Circuit Design - caused by insufficient suction, deficient flush circuit, and pumps unsuitable for the design service conditions
- 9% Poor Seal Selection - caused by the wrong materials or wrong configuration
- 8% Other

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[20] Presentation to the MIT Extended Cycle Project Group by Steve Jambor of John Crane, Inc., 24 April 1996, p. 80.

[21] Crane, p. 66.

6.3.2.1.2 Bearings

Bearing failures accounted for the second largest number of MFP reported failures. Of the 205 reported MFP failures, 35 were caused by bearing failures. The principal causes of bearing failure were misalignment or vibration in the pump causing excess bearing loads, and lube oil system related problems. Lube oil system related problems were reported as being principally caused by two major factors. First, contaminants in the oil (water or debris) which can damage bearing faces or reduce cooling to the bearing. Second, a complete loss of lube oil to the bearing which results in a short term catastrophic failure of the bearing babbit surfaces.

One attractive alternative currently being explored is the use of magnetic bearings. Magnetic bearings are self-aligning and require no lube oil, the leading cause of bearing failure. The U.S. Navy has started to use these types of bearings on their turbine generators and the Electric Power Research Institute (EPRI) is currently investigating their use on a wide range of pumps and turbines. The major drawback of magnetic bearings is that they are relatively expensive and would require equipment modifications to backfit them into existing components including the MFP.

6.3.2.1.3 Control Systems

Control systems were the third leading reported cause of MFP failures accounting for 20 of the 205 MFP failures which resulted in a plant trip, plant shutdown, or reduction in power. Additionally, control system failures were the cause of 18 of the 55 trips associated with MFP's in the review of LER feedwater system trips between 1985 and 1993. The principal cause of control system failures was problems associated with the lube oil. Similar to the bearing problems discussed above, loss of oil or loss of oil cleanliness was the root cause of control system failures.

6.3.2.1.4 Pump Structures

Unlike the other failure mechanisms discussed previously, pump structures are not as significant a contributor to the overall failure rate of the MFP, accounting for 16 of the 205 reported MFP failures which caused a plant trip, shutdown, or reduction in power. Pump structures include the pump shaft, impeller, and casing. These failure mechanisms are important though because of their impact on the plant capacity factor. Failures of the pump structure typically result in more severe damage to the pump. This generally causes the cost and time to repair the pump to be higher for this type of failure than any other kind. Most of the casing and shaft damage is the result of poor manufacturing techniques. The principal causes of impeller damage are vibration caused by pump misalignment, operation of the pump for significant periods of time at other than design conditions, and cavitation caused by insufficient suction pressures.

6.3.2.2 Major Root Causes of Failure

Based on research of MFP material records and discussions with pump experts there appears to be three major root causes of MFP failures. These include:

- Vibration Induced Failures
- System Cleanliness Failures
- Pump or System Design Failures

Each of these areas is discussed in more detail in the following sections.

6.3.2.2.1 Vibration Induced Failures

Vibration is probably the leading cause of failure in all types of rotating machinery including MFP's. Often vibration failures show up as failures in bearings, seals, or other pump internals. Vibration was the root cause of failure in 55 of the 205 MFP failures studied. Vibration is primarily caused by three major areas, misalignment, improper design, and operation of the pump at other than design conditions.

Misalignment can be caused by several factors. The first is obviously from an initial misalignment of the pump during installation or following repair. This can occur as a result of operator error, but is most likely the result of not accounting for the alignment differences when the pump is hot and cold. Proper alignment procedures should include both a cold and hot alignment, with the hot alignment being the most vital since this is the condition where the pump is most often operated. Advanced optical alignment techniques are available to assist technicians, but many pump experts say that these tools are not any better than the older reverse dial indicator method of pump alignment.

Misalignment can also be caused by nozzle loading. This is especially a problem in the nuclear industry where the large flow rates of the pumps requires very large suction and discharge piping. This piping, also experiences thermal expansion during plant heatup, and if not properly anchored or designed to allow for expansion will transmit nozzle loads to the pump which will move the pump out of alignment. Essentially, the pump should not be used as the anchor point for its suction and discharge piping. One leading pump manufacturer stated that solving the nozzle load issue was the critical factor in the long term reliable operation of nuclear MFP's.

The coupling between the pump and its driver is also a critical factor in the misalignment of MFP's. Couplings should be designed to absorb some misalignment differences between the pump and the driver. However, couplings which are designed to handle the largest amount of misalignment are not well suited to the high loads and high speeds required of the MFP's used in the nuclear industry. Several of the coupling failures found in the research were due to inadequate lubrication of the coupling itself.

Finally, thermal effects play a large role in MFP misalignment. Thermal effects manifest themselves in increased nozzle loads, but also play a major role in the misalignment of pumps which are improperly mounted. MFP's should be center mounted with the driver hard mounted to the foundation and the pump free to move axially on a sliding foot. Failure to properly lubricate this sliding foot area can result in pump misalignments due to thermal effects.

Improper design of the pump is also a leading cause of MFP vibration. There are too many areas of pump design which have the goal of reducing pump vibration to discuss here. However, there are two significant areas which warrant a brief discussion.

The first is the adjustment of the two gaps at the impeller periphery. The first gap, generally referred to as the "A" gap, is the gap between the sidewall of the pump casing and the impeller itself. This gap should be made as small as possible to prevent high pressure water at the impeller discharge from leaking back to the suction side of the pump. This leakage sets up recirculations in the pump which cause vibrations. However, reducing the "A" gap means that the clearances are so small that any misalignment of the pump will result in premature wearing of the pump wearing rings, setting up higher recirculation levels and thus more vibration. The second gap, commonly referred to as the "B" gap, is the gap between the impeller leading edge and diffuser or volute at the outlet to the pump. This gap should be increased to reduce the intensity of the interaction between the impeller and the diffuser or volute. Increasing this gap from three percent to five percent of impeller radius reduces the pressure pulsations and loads which cause vibration by more than half. However, increasing the "B" gap too much will result in a loss of pump efficiency.[22]

The second important design consideration in reducing the vibration levels of the MFP is to design the MFP so that it's best efficiency point corresponds to the normal operating conditions of the plant. As was stated previously, operations at this point are known to result in the lowest dynamic stresses in the pump and various pump components, lower risk of cavitation, and therefore longer lifetimes for pump components as well as reduced maintenance. However, most nuclear feed pumps are designed with additional flow margins because of safety considerations. Many plants were also originally designed with extra flow capability in case the plant wanted to upgrade the rated capacity of the plant at some later date. Both of these considerations result in MFP's whose BEP is not at the normal operating conditions of the pump. This condition can be corrected by "tuning" the pump. Tuning the pump involves shaving the impeller to change the pump characteristics so that the pump is operating at BEP at the normal operating conditions of the plant. Utility managers and plant designers should consider the trade-offs in increased pump reliability with the need for rarely used higher capacity capabilities.

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[22] Cooper, Paul, Wotring, Timothy, and Makay, Elemer, "Minimum Continuous Stable Flow in Feed Pumps". Ingersoll Rand Company, p. 2.

Pump operation is the last major contributor to vibration. Pump operation is analogous to the design issues surrounding BEP. Even if the pump is designed so that normal operations are not at the pump's BEP, operators should attempt to get as close as possible to BEP. This means that multiple MFP's should not be run at low demand conditions where only one MFP is required and that pump start ups should occur expeditiously while meeting all pump heatup requirements to minimize the time spent at low unstable flow conditions.

6.3.2.2.2 System Cleanliness Induced Failures

One of the leading causes, yet simplest root causes of failure is a lack of system cleanliness principally in lube oil or seal flushing systems. System cleanliness problems were the root cause of MFP failure in 35 of 205 MFP NPRDS failures which resulted in a plant trip, plant shutdown, or power reduction. While relatively simple to fix, cleanliness issues require constant attention. Lube oil system cleanliness can be improved through the use of filters and in-line purification systems. Seal water cleanliness can be improved through proper chemistry control and the proper pressure and flow rates to the seals.

6.3.2.3 Summary of MFP Root Causes of Failure

Table 6-3 provides a summary of the major root causes of 205 NPRDS MFP failures which caused a plant trip, shutdown, or reduction in power.

Summary of MFP Root Causes of Failure

Table 6 - 3

Root Cause	Number
Vibration Induced	55
Normal Wear	40
Cleanliness	35
Human Error	18
All Others	57

The principal recommendations for reducing these root causes of failure and maximizing the reliability of the MFP with the minimum cost include :

- Maintain system cleanliness in both lube oil and seal systems through daily attention to detail
- Reduce vibration by operating the MFP as close as possible to its Best Efficiency Point
- Perform proper hot and cold alignments of the MFP, check alignment frequently
- Check to ensure that the MFP is not being used as the anchor for suction and discharge piping and correct if possible
- Check to ensure that the pump is mounted on its foundation properly and that sliding feet are lubricated

There are several other recommendations which are design based or require some cost to implement. These include:

- Install the proper seals. Balanced, pusher, rotating seat seals with seal faces of Antimony filled carbon bearing upon reaction bonded silicon carbide offer the best combination of characterstics for MFP mechanical seals.
- Consider the installation of magnetic bearings if the backfit cost is not too high.
- Involve pipe and pump designers with plant engineers to reduce nozzle loading to the maximum extent possible.
- Consult with the plant MFP vendor to establish the optimum “A” and “B” gap clearances in the MFP.
- Tune the pump impeller to match the pump BEP with the normal plant operating conditions.
- Ensure plant operating procedures mandate the optimum combination of MFPs for the entire range of plant operating conditions.

6.4 Main Feed Pump Surveillance Program

The last of the three key issues that must be addressed in any overall strategy for reducing component or system forced outage rates is the component’s current surveillance program.

Surveillance programs should be studied to determine if the surveillances that must be performed with the component secured at intervals less than 48 months directly impact on the operation of the component, or whether these surveillance's main purpose is to ensure that protective devices and alarms for the component are functional. In the first case, as in the replacement of a pump impeller, these surveillances and their intervals have a direct impact on the reliability levels and forced outage rate contribution of the component or system. In the latter case, as in the case of the calibration of the MFP low suction trip, the surveillance performance is meant to aid in protecting the component or system from severe damage, but will not necessarily improve the overall reliability of the component. Table 6-4 provides a summary of the surveillances at the candidate PWR which are currently performed shutdown on the MFP at intervals less than 48 months. Note that all these surveillances have been previously resolved to either on-line performance or performance at 48 month intervals in Chapter 3.

Surveillances Currently Requiring MFP Shutdown

Table 6 - 4

Surveillance Description	Reliability or Control	Frequency
Turbine Bearing Oil and Low Vacuum Trips	Control	36 Months
Recirculation Flow Indication and Control	Control	18 Months
Turbine Governor Valve Position Calibration	Control	36 Months
Emergency Oil Pump Pressure Switch Calibration	Control	36 Months
Pressure Alarms and Speed Indication	Control	18 Months
Turbine Trip Header Oil Pressure Calibration	Control	36 Months
Suction Header Pressure Calibration	Control	18 Months
Speed Control Calibration	Control	18 Months
Turbine Overspeed Trip Mechanism Check	Control	18 Months

As can be seen from Table 6-4, all the surveillances performed inside of 48 month on the MFP at the candidate PWR are performed to ensure a control system is in calibration. This does not imply that these surveillances are unimportant. What it does mean, is that assuming all the

control surveillances remain in calibration, the pump is already expected to run reliably for at least 48 months based on the fact that there are no surveillances which replace or inspect major MFP components at intervals less than 48 months. Since all the control surveillances listed in Table 6-4 were previously resolved to a 48 month cycle, the surveillance program supports the contention that the MFP can be expected to run reliably for at least 48 months.

6.5 Summary of the Framework for Reducing Forced Outage Rates

This chapter has developed a framework for reducing forced outage rates of key plant components and applied that framework to the Main Feed Pump. The key areas that must be addressed in reducing component or system forced outage rates are:

- Current component or system reliability levels
- Major component/system failure mechanisms and their root causes
- Current surveillance program's impact on overall component or system reliability

For the Main Feed Pump, currently reliability levels were estimated using both LER trip history and NPRDS MFP plant trips, plant shutdowns, and power reductions. Average outage times for outages caused by MFP's were obtained from the NRC's outage database as an estimate of the average time to repair following a MFP failure. Based on this data, the MFP could be expected to run reliably for 48 months. This is further supported by an examination of the candidate PWR's MFP surveillance program. There are no surveillances performed on the MFP which replace or inspect major pump components at intervals of less than 48 months. Finally, the major failure mechanisms and their root causes are studied. Several recommendations are provided if implemented are likely to enhance the current reliability levels of the MFP.

The MFP is just one of many key plant components that must be studied in detail to determine their individual impact on the overall plant forced outage rate. Future studies should use the methodology developed in this chapter to focus on and improve those systems or components which have the largest contribution to the overall plant forced outage rate.

Chapter 7 - Other Fuel Cycle Extension Considerations

7.1 Introduction

This chapter presents a number of mostly managerial issues which are important considerations in achieving a 48 month cycle. The chapter is divided into three main sections; general issues, on-line surveillance performance issues, and surveillance interval extension issues.

7.2 General Issues

7.2.1 Management

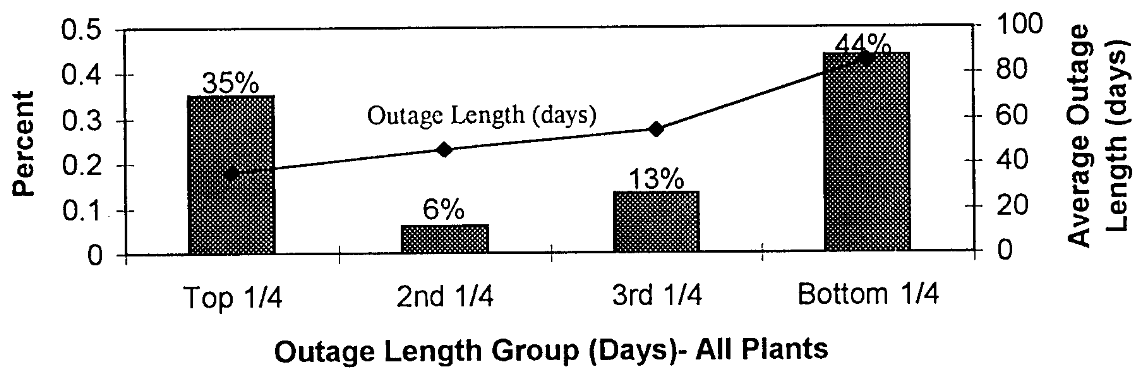
The top two priorities of plant management are safe and economic plant performance - in that order. However, in order to compete in a deregulating industry, economic operation has gone from a distant to a much closer second. Management must make nuclear plants cost competitive or they will not survive. The urgency of the situation calls for innovative ideas for improving plant economic performance. Fuel cycle extension is such an idea, but it is not an appropriate strategy for the poorest performing plants. For such plants, the benefits of extended fuel cycles can probably not be realized without extensive changes in basic management practices. Without these changes, extended cycles are likely to result in an economic penalty.

This hypothesis gains further credence when one analyzes the U.S. nuclear industry 1995 outage lengths. Although this one year does not provide enough data to make a statistically robust analysis, some interesting observations can be made about the data. For the purposes of this analysis, plants with operating cycles of greater than 20 months were considered to have extended cycle lengths. Assuming that cycle length has no impact on refueling outage lengths, the plants with pre-outage operating cycles greater than 20 months should be about evenly divided over the entire spectrum of refueling outage lengths ranging from 23 days (the best) to 152 days (the worst). In this one data set snapshot, this does not appear to be the case. The data leads one to the conclusion that extended cycle lengths may have a correlation with refueling outage lengths

for the poorer performing plants (as measured by total outage length) while it has no effect on the best performing plants. Figure 7-1 shows that longer cycle length plants make up a larger than expected percentage (36%) of the 1/4 of plants with the shortest outage lengths. But, they also make up a larger than expected percentage (44%) of the 1/4 of plants with the longest outage lengths. Additionally, the average outage length for the 1/4 of plants with the longest outage lengths rises dramatically as compared to the rise in average lengths seen over the first three 1/4 regions. This indicates that extending a plant's cycle length may exacerbate outage lengths for plants with poor performance records. These plants would perhaps do better by concentrating on improving performance at their current cycle lengths rather than risking the costs of an extended outage length following an extended operating cycle.

1995 Nuclear Industry Outage Lengths
Percent and Average Outage Lengths of Plants
with Pre-Outage Cycle Lengths Greater >20 Months
in each Quarter

Figure 7 - 1



While this data set is not large enough to draw absolute conclusions from, it does point out that utilities must consider in advance that longer run times may affect refueling outage lengths if all the possible ramifications of an extended cycle length are not considered. In order to capture the benefits of extended operation, the demands of high quality in equipment and operations grow rapidly.

Interestingly, the people in the industry currently most optimistic about extending fuel cycles are those who are also managing the top performing plants. These people believe that, in general, current plant hardware will support fuel cycle extension. And since these people are running plants at the highest levels of productivity in the industry, it is likely that they are sufficiently in tune with their systems.

Though they are not doing it with fuel cycle extension specifically in mind, many of the best plants are already pursuing the type of surveillance performance originality necessary to adopt an extended fuel cycle. They are actively looking for surveillances which can be performed on-line and surveillances whose historical records support performance interval extension. As a result, they are regularly petitioning the NRC for line item technical specification changes. These plants recognize that such pursuits ultimately cut costs regardless of cycle length. All plants should pursue optimization of their surveillance programs.

One of the best ways to optimize a plant's surveillance program is through implementation of the Improved Standard Technical Specifications (ISTS). In most cases, the ISTS's will result in fewer required surveillances. Just as important, the use of the ISTS will ensure timely NRC response when changes are requested to the technical specifications.

7.2.2 Modes of Transition

This thesis proposes a strategy for achieving a 48 month fuel cycle. The 48 month interval was chosen because it was within practical core load limits and yet is significantly longer than any cycle currently employed or currently contemplated within the U.S. nuclear industry. One of this thesis's primary objectives was to prove that the regulatory barriers to an extended fuel cycles could be overcome. However, the best method of achieving a 48 month cycle is probably not in one abrupt fuel cycle extension, but rather in incremental changes from 24 to 36 to 48 months.

From an engineering standpoint it is probably more prudent to adopt a 48 month operating cycle incrementally since the long term operating performance of many major plant components in the interval between 24 and 48 months is not well understood. By increasing cycle lengths incrementally, data on longer term operating performance and failure mechanisms can be gathered. With this data, maintenance, design, and operating strategies to support longer

operating cycles can then be developed. While abrupt transitions may be possible, a gradual transition to an extended cycle length is much more likely to be successful.

7.2.3 Mid-Cycle Maintenance Outages & Surveillance Performance Hotlists

The age and physical condition of some systems at some plants will create obstacles to a 48 month operating cycle. If a surveillance is important economically in terms of the Limiting Plant Event Frequency (LPEF), and cannot be performed either on-line or shutdown at 48 month intervals, a plant may need to shut down during the operating cycle to perform the surveillance. Chapter 4 provided a list of surveillances which are likely to fall into this category. Of these, Steam Generator Eddy Current testing and ESFAS testing take the longest to perform and are candidates for performance during a mid-cycle maintenance outage. Based on historical records, this mid-cycle outage is estimated to take on the order of 10-14 days.

Although it may be necessary, a planned mid-cycle maintenance outage erodes the capacity factor gains which are the impetus to the entire extended fuel cycle project, and should be avoided if possible. As an alternative, plants should be prepared to use reduced power windows or forced outages to accomplish Category C type surveillances as long as the surveillance performance does not unnecessarily extend the forced outage length. Since it typically takes a plant about two to three days to recover from a forced outage, there should be plenty time to complete the Category C surveillances identified in Chapter 4, with the exception of ESFAS testing and Steam Generator Eddy Current testing, if they have been pre-planned and can be started within a couple of hours notice of a forced outage. Given that the current cycle length record is less than 700 days, forced outage windows are likely to be available for most of the Category C surveillances.

As a concluding thought, as Chapter 3 shows, only 54 of the 3108 surveillances evaluated pose potential barriers to a 48 month fuel cycle.

7.2.4 Odd Length Surveillance Intervals Greater Than Target Cycle Length

A relatively minor issue, but one that can easily be overlooked, is that of odd length surveillance intervals. Odd length surveillances, are those surveillances performed shutdown, whose current performance intervals are longer multiples of the current cycle length, but whose performance intervals would not be multiples of an extended cycle length. For example, an electrical surveillances is currently performed every 72 months which is a multiple of the current cycle length of 18 months. If the cycle length is changed to 48 months, a decision must be made as to whether to perform the surveillance more frequently at 48 month intervals or attempt to technically justify extending the MOV performance interval to 96 months. Both options have potential benefits and drawbacks, although 96 months would obviously be a better goal so that the surveillance would not have to be performed every refueling outage. Another reason to aim for the 96 month performance interval is that some surveillances (such as operability tests of safety system motors) ultimately decrease component life expectancy because of the added wear resulting from surveillance performance. Consequently, somewhere in the fuel cycle transition process, engineering attention needs to be given to surveillances with odd length performance intervals. The total number of surveillances with odd length surveillance intervals greater than 48 months are identified in Chapter 3.

7.2.5 Radiation Exposure

Adopting a four year operating cycle may have an effect on the radiation exposure received by plant personnel. The yearly collective dose received from refueling outages will tend to decrease since the interval between refuelings will be extended and the number of surveillances performed during refueling outages will be reduced. However, increasing the number of surveillances performed on-line may increase the total collective dose since general area radiation levels are higher with the plant at power.

As an example of the possible changes in radiation dose from an extended cycle, the following data was taken from a local BWR:

24 Month BWR Radiation Data

Table 7- 1

Category	Dose
Refueling portion of the last outage	69 man rem
Non-refueling portion of the last outage	321 man-rem
Annual collective dose excluding refueling outages	100 man-rem
Average annual collective dose over 24 months	**300 man-rem** [(69+321+(2*100))/2

To compare the 24 month surveillance program average annual collective radiation dose to a possible 48 month surveillance program the following assumptions were made:

1. General area radiation levels during on-line operations are about twice those shutdown.
2. Half of the surveillances currently performed shutdown will be performed on-line and half will continue to be performed during shutdowns with the shutdown exposure half the on-line exposure.
3. There will be a 25% increase in refueling operation dose due to a loss of proficiency from performing refueling operations once every 48 months as compared to 24 months.
4. The average annual collective dose excluding refueling outages will remain unchanged.

Using these thumbrules, the approximate average annual collective dose from a 48 month cycle would be as follows:

Estimated 48 Month BWR Exposure

Table 7- 2

Category	Dose
Average annual collective dose excluding refueling outages (4 years)	400 man-rem
Refueling operations exposure (69 man-rem +25%)	86 man-rem
Non-refueling outage exposure (321/2)	160 man-rem
Non-refueling outage exposure shifted on-line (321/2)*2 general area)	320 man-rem
Total collective dose for a 48 month cycle (Sum of 1st four)	966 man-rem
Average annual collective dose for a 48 month cycle (966/4)	**242 man-rem**

These values are rough estimates and will change depending on the assumptions used, most notably the on-line general area radiation levels and the refueling operation dose. However, the rough estimates demonstrate that a drop in radiation exposure is possible from an extended fuel cycle and are within the INPO's goals for annual collective dose (250 man rem for a BWR by the year 2000). Relative changes in the dose estimates from a PWR should be considerably smaller.

7.2.6 Integrated Outage Teams

One of the concepts being looked at by the company which owns the candidate PWR is the use of integrated outage teams to reduce maintenance costs. In this concept, experts in particular fields are looked upon as resources for a series of plants within a network, as opposed to experts for one particular plant only. In this way, an expanded talent pool is available to address problems within the utility. Lessons learned and experience gained from one plant can be applied to other plants within the company to improve the performance of all the plants. Additionally, in an era of downsizing, having experts available for all plants within a utility means that the total workforce can be reduced. Integrated outage teams are particularly well suited for complex outage evolutions such as refueling operations or steam generator eddy current testing.

7.3 On-Line Performance Issues

7.3.1 Risk Monitors

On-line risk monitoring software such as Sentinel and Equipment Out of Service (EOOS) are being incorporated throughout the nuclear industry. These monitors are Probabilistic Risk Assessment (PRA) based tools which help to quantify the increased risks involved with taking systems and combinations of systems out of service while the plant is operating. Although not all U.S. plants are employing well developed risk monitors, risk monitors will undoubtedly play a role in the safe performance of the extensive on-line testing and maintenance activities needed to achieve a four year operating cycle.

Plant risk monitors are developed and maintained by PRA engineers. They are designed for use by both surveillance schedulers and plant operators. The monitors enable surveillance schedulers to quantify the risks involved with performing one or more maintenance or testing activities in a given plant mode. The schedulers can then optimize work schedules by managing the risk associated with the different activities. For the operator, the risk monitors identify which systems are most important to maintain operable given that another system is inoperable. For example, if a emergency diesel generator is taken off-line, a risk monitor would tell the operator what the overall increased risk is in terms of the Core Damage Frequency (CDF) and would identify the steam driven Emergency Feedwater Pump as the most valuable safety system which should be maintained operable.

Although PRA based risk tools which emphasize CDF are well developed, more effort must be concentrated on an economic Limited Plant Event Frequency (LPEF) tool. This tool would be an economics based PRA tool and include CDF as one of the limiting plant events because of its enormous economic impact. It could function as both an on-line monitor for operators to use and as a more detailed stand alone tool for planners to use when developing the entire surveillance program for a 48 month fuel cycle. The possible inputs and methodology for a PRA based economic LPEF tool are discussed in more detail in chapter 2.

7.3.2 NRC Perspective

The NRC supports the concept of on-line surveillance performance and recognizes its importance to the economic competitiveness of the nuclear industry. In contrast to refueling outages, more attention can be focused on the safe performance of on-line surveillances because there are not as many activities competing for the time and attention of plant personnel. In addition to the extra oversight and attention to detail which can be given to on-line surveillances performance, it is safer to perform some surveillances on-line. One example is the Residual Heat Removal (RHR) system. The system is not required with the plant at power. However, during refueling operations it is a vital decay heat removal source. Because of this, it is more risk

significant when the plant is shutdown than when the plant is operating. Therefore, RHR surveillances are safer if performed at power.

Probably the major concern the NRC has with on-line surveillance performance is that plant personnel often do not have a firm understanding of the consequences and possible contingencies required when a particular system is removed from service. To avoid this, plant management must instill the proper safety culture and take an active role in ensuring that all workers are thoroughly prepared prior to on-line surveillance performance.

7.3.3 Degradation from Over-Testing

The possible negative effects of increasing surveillance performance frequency for a surveillance which can now be performed on-line must be carefully understood. Surveillance performance frequency should not be arbitrarily increased. For example, human errors introduced during surveillance performance can cause a system which was performing well to experience problems upon return to operational status. Consequently, a thorough justification in terms of either LPEF or CDF should be made before increasing a surveillance's frequency. Poorly planned frequency increases could ultimately result in increases in either the LPEF or CDF.

7.4 Performance Interval Extension Issues

7.4.1 Quantification of Extension Justifications and Data Availability

The NRC's Generic Letter 91-04 identifies the documentation required to extend technical specification surveillance intervals to 24 months. In order to extend the calibration interval on instrumentation, a utility must present a detailed, quantified justification "in order to confirm that drift will not result in instrument errors that exceed the assumptions of the safety analysis." However, non-instrumentation surveillances requirements for interval extension justification are not as quantitative and can be based heavily on past material history and expert judgment. In addition to ensuring that the increased interval does not invalidate any assumption in the plant

licensing basis, the NRC requires that historical maintenance and surveillance data be checked to be sure that such records validate the expert opinion. In fact, Generic Letter 91-04 states that utilities "need not quantify the effect of the change in surveillance intervals on the availability of individual systems or components."

One of the likely reasons for not requiring a more quantified approach to performance interval extension justifications is the lack of solid data upon which to make quantitative judgments. The data deficiency is a problem in many sectors of the nuclear utility industry. Ultimately, the lack of data availability and trending is a problem which can be solved if given a high enough priority by management. Since it is reasonable to assume that expert judgment will not be sufficient to justify every non-instrumentation surveillance out to 48 months, this is a problem which must be solved if a four year cycle is to become a reality.

7.4.2 Insurance Costs and Vendor Guarantee Issues

Extending the interval between testing of some plant components may have an impact on the cost of insurance to the industry. Initial conversations with the Nuclear Mutual Limited (NML)[23] indicate that from a regulatory standpoint, that as long as the NRC agrees with the changes necessary to obtain a 48 month fuel cycle, that no rate changes would occur on the systems under the responsibility of the NRC. On the Balance of Plant (BOP) side, NML has developed loss control standards, agreed upon by the industry, which detail the required inspections and performance intervals for all major pieces of equipment. This includes such items as the Main Turbine and Main Feed Pumps. As long as the current inspection interval for these major components is greater than 48 months they will not have an impact on the insurance rates charged the utility. Any components with inspection intervals inside of 48 months will have to be studied further to determine any changes in the insurance rates charged a utility.

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[23] Phone conversation between Thomas Moore, MIT, and Greg Wilks, NML, of 1 May 1996.

7.5 Summary

This chapter presents a few of the many issues that must be considered prior to implementing an extended fuel cycle program. The main purpose of the chapter was to point out that even if technically feasible, the benefits of extended fuel cycles will depend just as much, if not more, on a proactive and forward thinking managerial approach to the myriad of issues that must be properly addressed to successfully implement an extended fuel cycle program. Many of the issues discussed here also have applicability to improved economic performance regardless of cycle length. Ultimately, strong management, and excellent operational and maintenance teams will be the key factors in whether the 48 month fuel cycle will provide the economic benefits touted here.

Chapter 8 Summary and Future Work

8.1 Summary

Heading into the 21st century the U.S. nuclear industry must be willing to expand the goal of each plant from safe performance, to safe and economic performance, and apply this type of thinking in all its decision making processes if it hopes to remain competitive in a deregulated electric power market. This thesis has focused on improving plant economic performance by developing a strategy for increasing plant cycle lengths to 48 months or more. The strategy addressed the key issues of matching the current regulatory and investment protection surveillance programs to a 48 month cycle, and determining the impact of 48 month cycles on component reliability and overall plant forced outage rates.

The goals and objectives of the thesis were to:

- Overcome the regulatory and investment protection barriers to extended cycle lengths
- Provide a systematic surveillance resolution procedure that utilities can use to prepare for extended cycle lengths
- Develop an initial framework for a key plant component to demonstrate how key plant components can operate for extended periods of time between maintenance without adversely impacting the plant forced outage rate.

The first step in meeting the stated goals and objectives of the thesis was to develop a detailed methodology for resolving the current regulatory and investment protection surveillance programs to a 48 month cycle. The methodology produced recommendations for each surveillance regarding its compatibility to a 48 month fuel cycle. The three major categories of recommendations were:

- Category A Surveillance - A candidate for on-line performance.

- Category B Surveillance - A candidate for performance interval extension to 48 months.
- Category C Surveillance - A potential barrier to a 48 month cycle requiring further study.

As part of this methodology an economic optimization model was developed. The purpose of the economic optimization model was to recognize that many surveillances fit into both the on-line performance and extended interval performance categories, and that there is an optimum mix of these surveillances which produces maximum economic benefit while maintaining current plant risk levels. The economic optimization model also introduced the concept of the Limiting Plant Event (LPE). LPE's, which include all events with a significant economic impact, define the entire set of risks which must be controlled to achieve economic success. Since the rationale behind any length fuel cycle extension program is improved economic performance, the LPE frequency is the critical factor that must be considered in any surveillance resolution program.

To meet the first two stated goals and objectives of the thesis, the surveillance resolution methodology was applied to the regulatory and investment protection surveillance programs at an operating Pressurized Water Reactor (PWR). All surveillances which were currently precluding a 48 month fuel cycle were considered. Of the 3,108 surveillances currently performed shutdown at intervals less than 48 months, 2,673 are likely candidates for on-line performance, 381 are likely candidates for performance interval extension to 48 months, and 54 remain as likely barriers to a 48 month fuel cycle. Of the 2,673 surveillances which are candidates for on-line performance, 67 require a reduced power window for on-line performance. Performance of these surveillances during a reduced power window is likely to produce a net economic benefit as compared to the shutdown performance option, if shutdown performance of these surveillances takes more than 2.9 days. A recommended performance sequence for these reduced power window surveillances and economic analysis is included.

The 54 surveillances which are potential barriers to an extended fuel cycle (Category C) are evenly divided between the regulatory and investment protection

surveillance programs. On the regulatory side, several motor-operated safety injection valves and steam generator eddy current testing are potential barriers to a 48 month fuel cycle. On the investment protection side, condenser waterbox maintenance and several reactor coolant pumps surveillances also pose likely barriers to a 48 month fuel cycle. Relief valve testing is a common regulatory and investment protection surveillance barrier to extended cycles. Based on a review of historical performance times, the Category C surveillances require about 12-14 days to complete with the plant shutdown.

As part of an actual PWR 24 month fuel cycle extension program, a technical justification for extending the testing interval of the Primary Component Cooling Water (PCCW) from 18 to 24 months was developed. Additionally, as part of this effort, detailed instructions for the completion of technical evaluations suitable for submission to the Nuclear Regulatory Commission (NRC) were drafted. Both are included in this thesis to demonstrate the level of effort required to perform a complete 48 month fuel cycle surveillance resolution project.

To meet the final goal and objective of the thesis, a three part methodology was developed for studying the impact of key plant components on the overall plant forced outage rate. The thesis forced outage rate goal was derived from the current Institute for Nuclear Power Operations (INPO) forced outage rate goal of less than 3%. The methodology for studying key plant components involved:

- Determining the current component or system reliability levels
- Determining the major component/system failure mechanisms, the root causes of failure, and providing recommendations for their correction
- Determining the current surveillance program's impact on overall component or system reliability

The methodology was first applied to the Main Feed Pump (MFP). The MFP was chosen because of its relative simplicity, access to pump experts, and the availability of some actual failure rate data. Using data obtained from a review of Licensee Event Reports (LER) and the Nuclear Plant Reliability Data System (NRPDS) MFP failure rates of $6.46*10^{-6}$/hr and $1.57*10^{-5}$/hr respectively were calculated. When combined with an

estimated average time to repair of 53 hours obtained from a review of the NRC maintained industry outage database, both the LER and NPRDS derived failure rates were well under the calculated failure rate of $3*10^{-4}$/hr needed to achieve a system 97% capacity factor.

The major MFP failure mechanisms and their root causes were determined based on a review of feed pump failure data and extensive interviews with industry representatives, pump consultants, pump vendors, and major sub-component vendors. The major causes of MFP failures were the seals, bearings, pump structures, and the speed control systems. The major root causes of these failures were vibration, system cleanliness, and improper system design.

The current surveillance program at the candidate PWR was reviewed to determine its impact on MFP reliability and the MFP contribution to the overall plant forced outage rate. All surveillances performed at frequencies of less than 48 months involved the testing of various MFP trips, alarms, and speed control systems. These types of surveillances are designed to prevent damage to the MFP from abnormal plant conditions, but in general do not contribute to the overall reliability levels of the pump. All surveillances which inspected or replaced major MFP components such as bearings, seals, or impellers, which would affect the long term reliability of the MFP are performed at intervals greater than 48 months. Based on the review of the MFP surveillance program in conjunction with the calculated failure rates and failure mechanism review, it was concluded that the MFP could be expect to operate reliably on a 48 month fuel cycle without adversely impacting the overall plant forced outage rate.

Finally, many of the important managerial issues related to extended cycles were studied. One of the most significant findings was that there appears to be a relationship between operating cycle length and the subsequent refueling outage length. Plants that had operating cycles greater than 20 months tended to be either amongst the 25% of plants with the shortest refueling outage lengths or in the 25% of plants with the longest refueling outage lengths. This leads to the conclusion that the best performing plants will tend to receive the greatest economic benefit from an extended fuel cycle, while the worst performing plants may actually incur an economic penalty by extending their cycle lengths.

The worst performing plants should concentrate on improving their performance at their current cycle length before considering moving to an extended cycle length.

8.2 Future Work

As a result of some of the findings of this thesis, there is significant future work that must be accomplished by the MIT Extended Fuel Cycle project to establish the technical basis upon which a utility decision to explore implementing an extended fuel cycle could be based. The future work includes a wide range of areas from economics to plant safety.

Chapter 2 (Surveillance Resolution Methodology) introduced the concept of an Economic Optimization Model and the Limiting Plant Event Frequency (LPEF) as tools in making economic decisions. Actual development of this model using modern linear programming and probabilistic risk assessment techniques should be investigated. Further research should also be considered on quantifying the LPEF and the impact of plant configuration changes on the LPEF. This work should be similar in scope to previous work done on Core Damage Frequency (CDF) such as in the RISKMAN software. Since CDF is only a subset of the entire set of LPE's, developing this tool will require significant time and resources.

Chapter 3 (Surveillance Categorization) qualitatively applied the methodology developed in Chapter 2 to determine the optimum performance mode of each surveillance. As part of this effort, research must be conducted on developing a quantitative method for determining the optimum performance interval for all surveillances. Determining the optimum performance interval for both the surveillances that can be performed on-line and those that must be performed shutdown will improve economic performance by reducing the amount of maintenance that must be performed. Reducing the amount of maintenance performed is also likely to result in an additional reliability payoff by reducing the impact of human error on component reliability.

Chapter 4 (Category C Surveillances) provided a complete description of the 54 individual surveillances identified as potential barriers to a 48 month cycle. Some possible solutions to these surveillance barriers were proposed. However, more detailed

engineering work needs to be done on each of these surveillances. The detailed engineering work should propose a range of possible solutions utilizing existing and evolving state-of-the-art technologies. All engineering solutions must consider the cost of implementing the proposed changes.

Chapter 6 (A Framework for Reducing Forced Outage Rates) proposed a framework for reducing plant forced outage rates. One of the key factors in prioritizing those components which should be studied first is the availability and accuracy of component failure rate data. Several databases of data exist such as the Licensee Event Reports (LER), Nuclear Plant Reliability Data System (NPRDS), and the NRC's "gray book" which keeps track of industry wide outages and their causes. These databases need to be normalized so that the data sources are compatible with each other. Only by developing consistency amongst the data sources can accurate conclusions be drawn. Additional sources of data must continue to be pursued. With the data currently available, future work should study the prioritized component list and develop recommended solutions for reducing forced outage rates. The goal of the each study should be to reduce any time dependent component of failure over a 48 month cycle interval.

Additional research should also continue on some of the more subtle management issues that must be addressed in order to make a smooth transition from current operating lengths to an extended operating cycle. A closer examination of the impact of cycle lengths on the nuclear industry's insurance rates must be conducted.

Finally, a detailed economic analysis must be performed that incorporates the costs of an extended cycle core with the potential operations and maintenance savings from extended cycle operations. Only if the nuclear industry is convinced that there is a short term (three to four year) payoff of an extended cycle core will extended cycle lengths ever be seriously studied for adoption.

Appendix A Instructions for Technical Evaluations

Instructions for Completion of

Fuel Cycle Extension

Technical Evaluations

A.1 Introduction

The purpose of the technical evaluation is to provide a technical justification to the Nuclear Regulatory Commission for extending the performance interval of a surveillance in support of a fuel cycle extension project. This instruction outlines the methodology necessary to meet the requirements of NRC Generic Letter 91-04 "Changes in Technical Specification Surveillance Intervals to Accommodate a 24-Month Fuel Cycle" and is adaptable to fuel cycles of various lengths. All personnel performing technical evaluations should read and be familiar with the requirements of Generic Letter 91-04 before attempting to complete a technical evaluation.

For all evaluations, the evaluator must demonstrate the following:

- The effect on plant safety is insignificant, and;
- Historical preventative and corrective maintenance records, surveillance data, and other surveillances performed on system components support this conclusion, and;
- The performance of the surveillance at the bounding surveillance interval limit will not invalidate any assumption in the plant licensing basis.

Generic Letter 91-04 also addresses specific information that is required for surveillances involving Steam Generator inspections (PWR only), containment leak tests, and instrument drift. Evaluators involved with surveillances in these particular areas must ensure they understand any additional Generic letter requirements they must address in their evaluation.

A.2 Methodology

Section 8.2.2 of this report is a technical evaluation completed for PWR technical specification 4.7.3.b. "Primary Component Cooling (PCC) Automatic Valve Actuation". It provides a general format for technical evaluations suitable for submission to the NRC. A more detailed discussion of each section of the technical evaluation follows.

A.2.1 Section I - Technical Evaluation Conclusion

State the current technical specification frequency and whether or not the surveillance will support performance interval extension. If the evaluation supports extension of the surveillance interval, the wording of this paragraph should closely follow the wording shown in section 8.2.2 which is derived from Generic Letter 91-04.

A.2.2 Section II - Description of Change

Briefly describe the surveillance being evaluated and the individual components being tested if applicable. Individual components tested should be added as an attachment to the base report. The plant's Final Safety Analysis Report (FSAR) provides an excellent reference description of the system and components involved in the evaluation. A description of the change requested to the current technical specification should follow.

A.2.3 Section IIA - Open Items Section

During the course of the evaluation, identify any potential conflicts with current operations or maintenance practices that would result from extending a surveillance performance interval. For instance, the PWR technical evaluation of section 8.2.2, performed on the PCC automatic valve surveillance, clearly supported extending the performance interval from 18 to 24 months. However, during the course of the evaluation, several maintenance items currently performed at multiples of 18 months (36,48,etc.) were identified which will have to be evaluated to determine the optimum performance interval consistent with a 24 month cycle (24, 48, 72, etc.). MOV's for example are lubricated every 36 months. Half of the valves are lubricated every 18 months to balance the work load. If it is not possible to extend the current performance

interval for lubrication from 36 to 48 months, than the lubrication performance interval may have to be shortened to 24 months and all MOV's lubricated every outage. This may impact the length of the refueling outage and negate any benefits gained from transitioning to a 24 month fuel cycle when the total surveillance package is considered. This is an in house section to be used by the fuel cycle extension coordinator. Once the potential conflicts are resolved this section should be deleted prior to submission to the NRC.

A.2.4 Section III - Evaluation of Change

This is the most important section of the evaluation and forms the basis for the evaluation final conclusions. There are two major parts to this section, a potential system failure mode analysis to analyze possible problems that might occur beyond the current performance interval, and a review of the system/component past performance history. The methodology needed to complete each section is described in more detail below. A checklist is included at the end of this instruction to assist in performing this section.

A.2.4.1 Potential System Failure Modes

Evaluate the following areas:

- What is the purpose of the surveillance?

For example, the purpose of the PWR PCC Automatic Valve Actuation surveillance is to confirm that if an accident occurs which requires an Engineered Safety Feature signal, the signal flows from the instrument, to a signal processor, to the motor for each required valve, and that the motor energizes and positions the valve within design time limits.

- What could prevent the system/components from performing their function, and are there time dependent failure on the interval of concern?

This section does not require a detailed failure effect mode analysis (FEMA) but should consider the major ways the system could fail. For example, for the PCC Automatic Valve Actuation surveillance, the system would fail to perform its function if

the sensor failed, the signal path or logic processor failed, the motor for any valve failed, or any valve mechanically failed to operate.

- Are other surveillances performed on a more frequent basis than the surveillance being evaluated which confirm the proper operation of individual portions of the system?

For example, for the PCC Automatic Valve Actuation surveillance, most of the valves are stroked, and the signal path confirmed on a quarterly basis to meet Inservice Testing requirements. The sensors can be checked to confirm they are operating properly by comparing redundant channel readings on operating logs.

- For any parts of the system not checked on a more frequent basis by other surveillances, would a time dependent failure be expected to occur during the interval between the old and new performance intervals?

To evaluate this section one should consider the margin between the actual performance of the system to its design basis performance limits, the operating environment of the components, and whether this environment would be expected to cause a prompt jump in failure probability during the interval extension. Comparing performance data from shorter previously used cycle lengths to the current cycle length may provide a useful baseline of any possible time dependent degradation in performance.

- What is the operating environment of the system/component?

Components that operate under high temperature, humidity, or radiation conditions may be more susceptible to time dependent failure modes on the interval of concern as compared to other similar components not subject to the same harsh environmental conditions. The environmental qualification (EQ) of the components should be verified with system engineers and EQ personnel.

A.2.4.2 Performance History

The performance history section should be further subdivided into four specific sections.

- Surveillance results
- Corrective maintenance frequency and type
- Preventative maintenance records
- System Engineer consultation

A.2.4.2.a Surveillance results Compile and review the results of all previous surveillance performances. Evaluate whether these surveillance results support a fuel cycle extension. Past surveillance results as shown in attachment 2 in section 8.2.2 may be obtained through the individual plant databases.

A.2.4.2.b Corrective maintenance frequency and type Compile and review the corrective maintenance history for the system being evaluated. The purpose of the review is to identify any potential failures which appear to be of a time dependent nature and which might be expected to occur inside the interval of concern.

A.2.4.2.c Preventative Maintenance Records The purpose of this review is to ensure that there are no other preventative maintenance activities performed on the system/component with performance intervals in either years or refueling interval multiples which would interfere with extending the surveillance interval.

A.2.4.2.d System Engineer Consultation. System engineers are an important source of information. They should be consulted early on in the evaluation process to obtain their opinions on the feasibility of extending the surveillance performance interval and to ensure that all pertinent sources of information necessary to complete the evaluation are being used. They should also be consulted near the end of the process to obtain comments and opinions on the rough draft of the evaluation before final submittal.

A.2.5 Section IV- Significant Hazards Evaluation

Complete this evaluation in accordance with 10CFR50.92. This part of the evaluation forms the basis for the licensing department's request for interval extension to the NRC. The evaluation <u>must</u> address the following:

(1) The proposed change does not involve a significant increase in the probability or consequences of an accident previously evaluated.

(2) The proposed change does not create the possibility of a new or different kind of accident from any accident previously evaluated

(3) The proposed change does not involve a significant reduction in a margin of safety

Section 5.2 of this report provides an example of the format and information required in this section.

A.2.6 Section V - Sources of Information

The following sources of information should be used to complete the technical evaluation:

- Station Technical Specifications
- Station Final Safety Analysis Report
- Station surveillance procedures
- System drawings
- System engineers
- Environmental Qualification engineers
- Annual System Performance Reports
- Generic Letter 91-04 "Changes in Technical Specification Surveillance Intervals to Accommodate a 24-Month Fuel Cycle"

Fuel Cycle Extension
Technical Evaluation Checklist

Failure Mode Analysis	Yes	No
-Operating environment of the component/system will not contribute to time dependent failures		
-Potential failure modes of components tested by the surveillance do not have time dependent failures that are so short that they would be expected to occur on the interval of concern		
-Failure probability analyzed based on plant and industry data		
-Affect of failure has been analyzed		
-Components that are not checked by other surveillances on a more frequent basis do not have time dependent failure modes that would be expected to occur on the interval of concern		
-Other surveillances are performed on system components on a more frequent basis which confirm continued component performance		
-Is the component or system stand alone, if not, do support systems performance support interval extension?		
Performance History Analysis	----	----
-Results of past surveillance testing supports		
-Corrective maintenance history supports a conclusion that there have been no failures of a time dependent nature		
-Other preventative maintenance performed on the system does not prevent interval extension		
-System Engineers and system experts support the conclusion that the surveillance interval can be safely extended		
Plant Data Required		
Planned Maintenance History (Tech Spec)		
Corrective Maintenance History		
Planned System Maintenance (Tech Spec)		
Planned System Maintenance (Non-Tech Spec)		